technical note

Cold Regions Research and Engineering Laboratory Tests on the New Generation Runway Visual Range (RVR) Look-Down Visibility Sensor (VS)

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September 1998

DOT/FAA/CT-TN98/22

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-TN98/22		

4. Title and Subtitle

Cold Regions Research and Engineering Laboratory Tests on the New Generation Runway Visual Range (RVR) Look-Down Visibility Sensor (VS)

5. Report Date

September 1998

6. Performing Organization Code

ACT-320

7. Author(s)

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8. Performing Organization Report No.

DOT/FAA/CT-TN98/22

9. Performing Organization Name and Address

U.S. Department of Transportation
Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, N.J. 08405

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

U.S. Department of Transportation
Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, N.J. 08405

13. Type of Report and Period Covered

Technical Note

14. Sponsoring Agency Code

15. Supplementary Notes

This effort was performed in cooperation with Federal Aviation Administration William J. Hughes Technical Center and project personnel from Raytheon Service Co. in Pleasantville, New Jersey.

16. Abstract

This report discusses testing and results of an evaluation performed on the New Generation Runway Visual Range (RVR) Visibility Sensor (VS). Extensive testing was conducted on the sensor at the Cold Regions Research and Engineering Laboratories (CRREL) during a 6-week period from July 1993, to August 1993. The CRREL test effort was intended to determine if modifications to the New Generation RVR VS would eliminate or significantly reduce problems including:

1. VS shutdowns during precipitation,
2. Accuracy deficiencies due to icing and snow clogging of the VS window,
3. Discrepancies in RVR readings during low-visibility conditions, and
4. The need for VS recalibration for fog and snow events.

Most significant of the New Generation RVR VS modifications was the reorientation of the sensor to a downward-looking direction, i.e., Look-Down configuration. This change was intended to reduce precipitation impinging on the VS window.

Conclusions from CRREL testing included the following:

1. The Look-Down configuration significantly increases sensor resistance to snow and ice clogging,
2. Combining the Look-Down configuration with "End-Loaded" heater blankets significantly increases sensor recovery from snow/ice-clogging conditions,
3. Controlling the VS heaters from the transmitter does not appear to significantly reduce sensor icing resistance,
4. For large snow rates, i.e., $\geq$ 48 oz./minute, VS resistance to snow/ice-clogging conditions appears to improve by deactivating the VS heaters at ambient temperatures just below freezing.

17. Key Words

Window Contamination, Snow-Clogging Rate
Look-Down VS, Look-Out VS
Blowing Snow Test
Wind Tunnel

18. Distribution Statement

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19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	96	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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EXECUTIVE SUMMARY

This report discusses results of an evaluation conducted on the New Generation Runway Visual Range (RVR) Visibility Sensor (VS). Extensive testing was performed at the Cold Regions Research and Engineering Laboratories (CRREL) from July 1993, to August 1993.

Prior to the test, significant problems were observed in RVR sensor performance during inclement weather conditions. The problems lead to significant degradation in the operation of the New Generation RVR. The problems included the following:

1. The need for VS recalibration to provide proper operation during fog and snow events;

2. VS operational shutdowns during precipitation;

3. Accuracy degradation due to snow/ice-clogging on the VS window; and

4. Discrepancies in RVR readings during nonprecipitation related low-visibility conditions.

Initial software modifications in response to these problems were unsuccessful in significantly improving sensor performance. As a result, additional hardware and software changes were made to correct the deficiencies.

Most significant in the hardware changes was the reorientation of the VS heads. Instead of a parallel to the ground orientation, the new design orients sensor optics in a downward direction. This modification was made primarily to reduce the amount of precipitation that could impinge on the VS window. The change was also designed to eliminate the need for recalibrating the sensor for fog and snow events.

Conclusions from CRREL testing include the following:

1. The new VS head orientation significantly increases sensor resistance to snow/ice-clogging;

2. The combination of the Look-Down configuration and the end loaded heater blanket significantly increases sensor recovery time from snow/ice-clogging conditions;

3. Controlling the VS heaters from the transmitter does not appear to significantly reduce sensor icing resistance; and

4. For large snow rates, i.e., $\geq$ 48 oz./minute, VS resistance to snow/ice-clogging appears to improve by deactivating the VS heaters at ambient temperatures just below freezing.

1. INTRODUCTION.

This report details results of tests performed on the New Generation Runway Visual Range (RVR) Look-Down Visibility Sensor (VS). Testing was conducted at the Cold Regions Research and Engineering Laboratories (CRREL) in Hanover, New Hampshire, during a 6-week period. The test period which commenced in July 1993, and ended in August 1993, included three separate sessions each lasting approximately 1 week.

1.1 PURPOSE.

The purpose of this report is to provide results of the CRREL tests performed on the Look-Down VS. The report is also intended to provide rationale for some New Generation RVR design changes such as the reorientation of the VS heads.

1.2 SCOPE.

This report will detail sensor configuration, equipment, test procedures, and results of the Look-Down VS evaluation. Diagrams are provided for each test scenario to supplement discussions in the test descriptions. Conclusions and comments are offered following a description of the test conduct. Final recommendations are provided at the end of the report.

Although CRREL tests also included evaluations of the original Look-Out VS and the Ambient Light Sensor (ALS), this report will focus on the new sensor which was first released during the CRREL testing period. Commonly referred to by the direction of its optics, the new sensor was designated the Look-Down VS. Paragraph 1.3.3 discusses the rationale for changing the hardware design of the VS from the Look-Out to the Look-Down configuration.

1.3 BACKGROUND.

1.3.1 CRREL.

The CRREL is an U.S. Army owned complex located in Hanover, New Hampshire. It has the capability to simulate various types of cold weather phenomenon including high winds, snow, freezing rain, and sub-zero temperatures. The complex has several laboratories varying in size and capability. Due to the laboratory capabilities and personnel experience, CRREL was selected as a site for evaluating performance of the RVR VS. CRREL testing was designed to assess the effectiveness of modifications such as heater blankets, hood-orientation, and window contamination filters made on the VS. This assessment was made primarily by simulating the weather conditions known to cause sensor performance problems and documenting the results. For example, since snow clogging and icing of the VS window was a known problem, various simulations of blowing snow conditions were produced to evaluate design changes and obtain additional data on the problem.

1.3.2 Blowing Precipitation Problems with the Original VS.

The Look-Out VS, utilized transmitter (Tx) and receiver (Rx) components that were oriented parallel to the ground (figure 1). This design configuration experienced sensor performance problems during precipitation events.

For example, the Look-Out VS clogged severely during three snow events in March and April of 1992, at St. Johns, Newfoundland. In two of the events, whiteout conditions existed with winds reaching 30 knots and temperatures below 15° F. In the third event, temperatures were just below freezing and clogging occurred after a long period of blowing snow.

During the events, snow was observed to accumulate on unheated areas on the underside of the sensor hood (figure 2). Snow clogging was also noted on the sensor window. Because of the sensor forward-scatter technology[1], light impediments (e.g., VS clogging) can result in higher than actual RVR readings.

In other field tests, blowing precipitation produced large window contamination signals in the Look-Out VS and the ALS. These window signals, which are actually voltage levels representing the amount of debris/precipitation on the window, were often large enough to exceed sensor software alarm limits and as a result, sensor and system shutdowns occurred for extended periods.

1.3.3 RVR Visibility Sensor Modifications.

Following a review of RVR VS performance at St. Johns, Newfoundland, and reports of precipitation related outages at other test sites, it was decided that modifications to the VS would be required to correct the observed problems. For risk

[1] The forward-scatter sensor relies on transmitted light being directed into the Rx to determine a decrease in visibility. The more transmitted light not reaching the Rx is interpreted as higher visibility for the sensor.

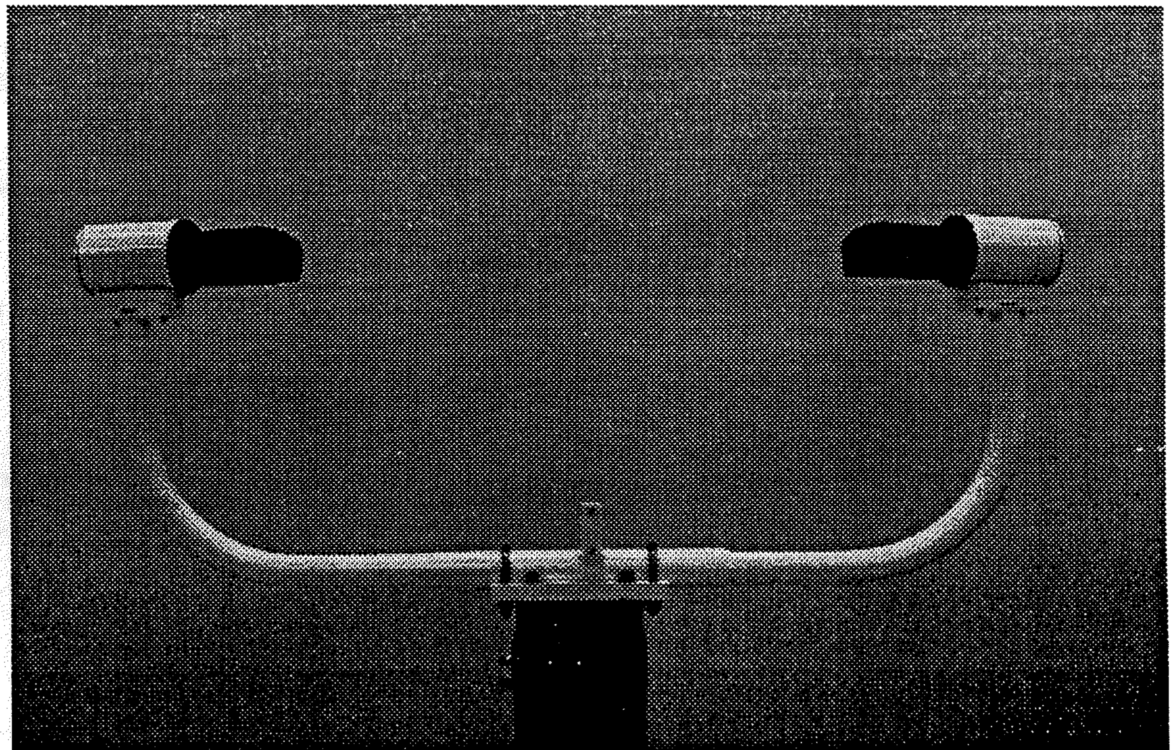

FIGURE 1. LOOK-OUT VS

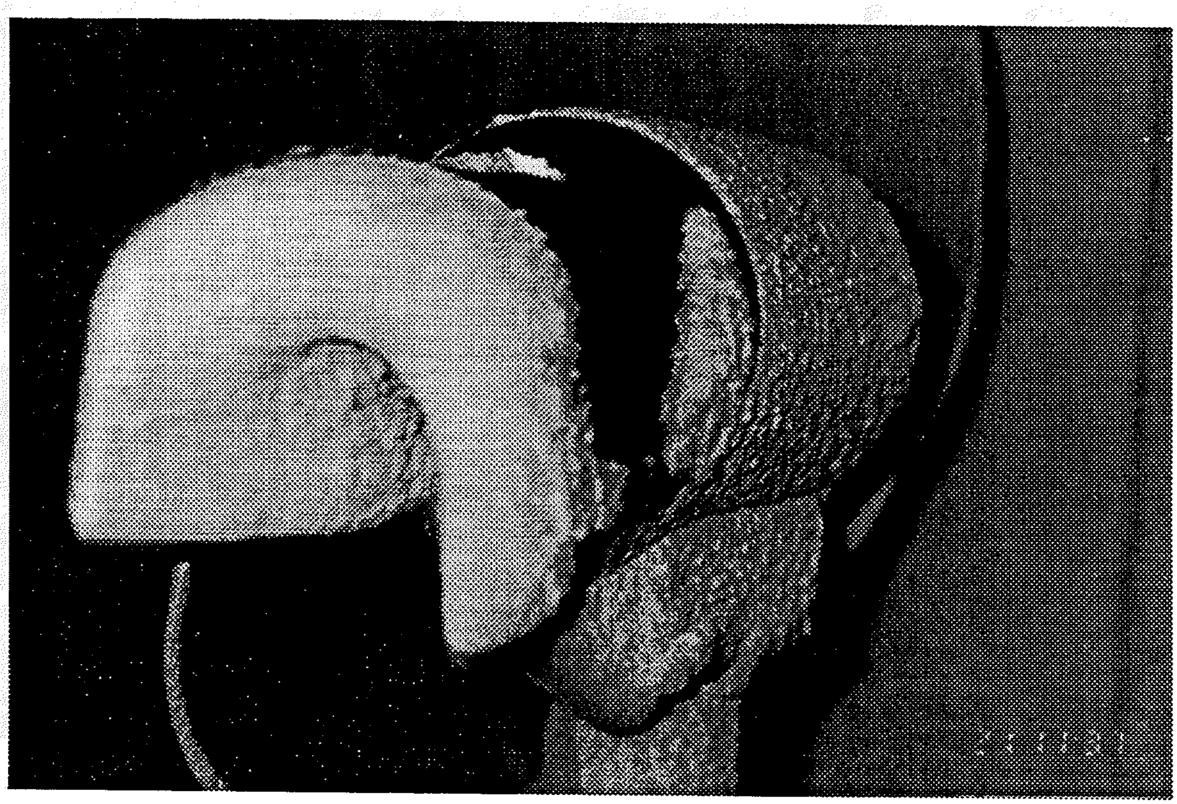

FIGURE 2. VS SNOW CLOGGING

reduction purposes, a dual path approach was taken to compare results of the modifications.

The first path consisted of software and heater modifications to the Look-Out VS. These modifications were intended to make the sensor more immune to the effects of precipitation striking the optics on the window and to prevent snow from collecting under the sensor hood.

The second path consisted of creating a new sensor with heads oriented downwards (i.e., Look-Down VS) instead of parallel to the ground. Modifications also included an extended hood with conformal heaters. The Look-Down orientation was intended to prevent precipitation from reaching the window and the underside of the sensor hood. An added benefit of the Look-Down configuration was that equal calibration for snow and fog could be achieved by orienting the heads at a particular angle. Analysis performed by the Volpe National Transportation Systems Center (VNTSC) revealed the optimum sensor angle to be 42°. This angle is measured by the intersection of the Tx infra-red light beam and the Rx field of view centerline. Figure 3 illustrates Look-Down VS components, the Tx beam, and the Rx field of view.

2. REFERENCE DOCUMENTS.

This report was developed in accordance with Acquisition Management System Test and Evaluation Guidelines, dated July 18, 1997, and the New Generation RVR System Specification--FAA-E-2772.

3. SYSTEM DESCRIPTION.

3.1 MISSION REVIEW.

The New Generation RVR is designed to replace transmissometer systems, e.g., Tasker 400, currently in use at U.S. airports. It will provide a measurement of runway visual range at specific points along a precision runway in support of instrument landings during Category I, II, and IIIa/b visibility conditions (specification FAA-E-2772).

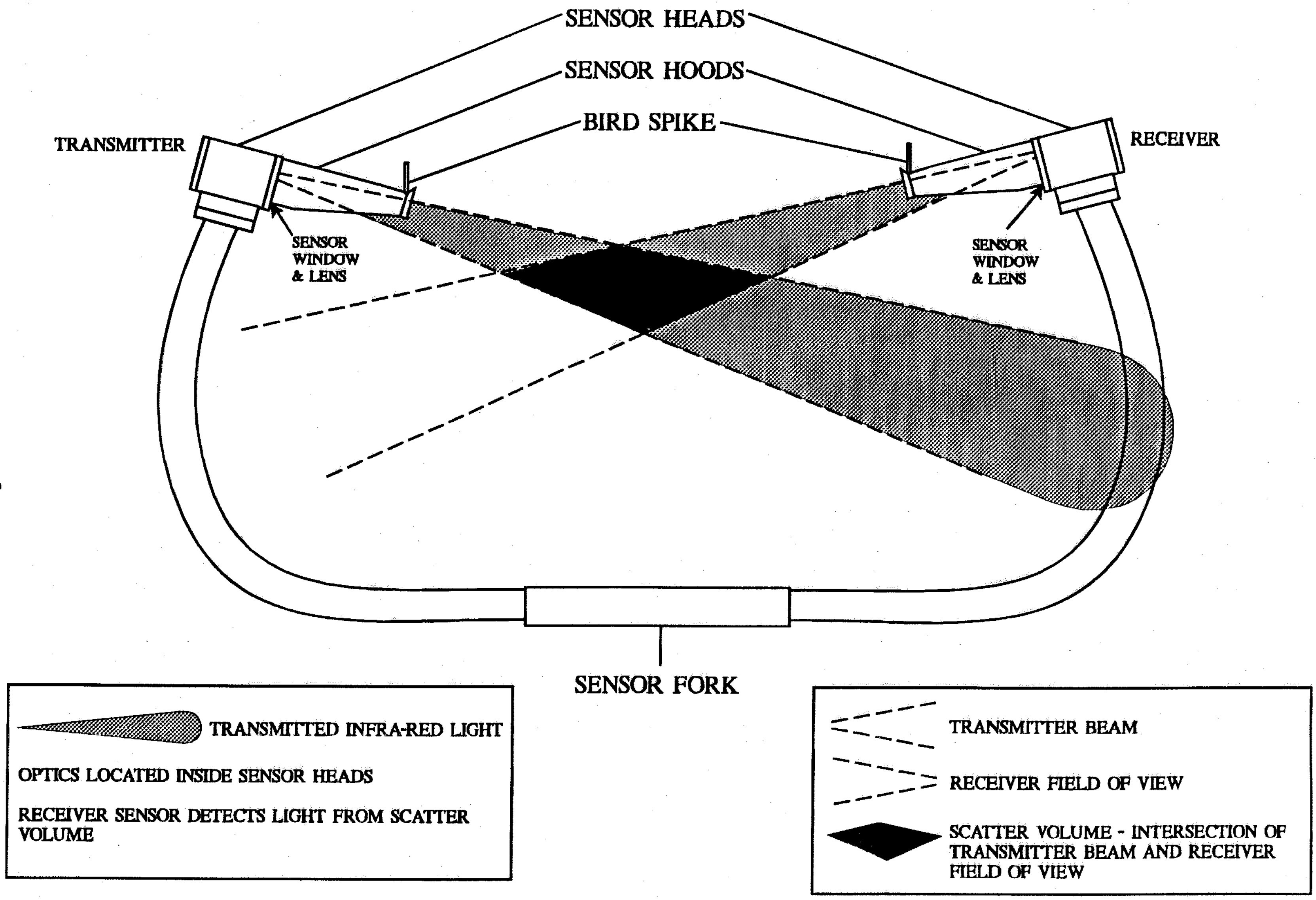

FIGURE 3. LOOK-DOWN VISIBILITY SENSOR COMPONENTS

The functions of the RVR include determination of the following:

a. Atmospheric scattering coefficients,
b. Ambient light intensity, and
c. Runway light settings.

This information is processed to yield distances that a pilot can expect to see along the departure or approach path of a runway. The New Generation RVR equipment will decrease the maintenance load and installation difficulties associated with current RVR system designs. Future expansion capabilities will be easier and less costly.

3.2 TEST SYSTEM CONFIGURATION.

The following New Generation RVR components were used in the system configuration:

a. VS (2). One Look-Down and one Look-Out configuration, installed inside chamber laboratory;

b. ALS (1). Installed inside chamber laboratory;

c. Data Processing Unit (DPU) (1). Installed outside chamber laboratory; and

d. Sensor Interface Electronics (SIE) Enclosure (3). Installed inside chamber laboratory.

3.2.1 VS Hardware.

As mentioned, CRREL testing was essentially an evaluation of RVR sensor components, and in particular the VS. Several VS prototypes were evaluated. Although the primary distinction in prototypes was sensor orientation, i.e., Look-Down or Look-Out, hood heaters varying in size and capability were combined with these orientations. Table 1 identifies VS hardware components and the dates used.

TABLE 1. VS HEATING ELEMENT PROTOTYPES

COMPONENT/HARDWARE	TEST PERIOD
Look-Out VS/50 watt heater "half-size" heating element	July 19 - July 26, 1993
Look-Out VS/85 watt heater "full-size" heating element	August 2 - August 26, 1993
Look-Down[2] VS/150 watt heater "end-loaded" heating element	August 5 - August 26, 1993

3.2.1.1 VS Hood Heater Prototypes.

The following subparagraphs provide a brief explanation of several hood-heating prototypes used during VS testing.

3.2.1.1.1 Half-Size Heating Element.

This refers to a heater in the form of a blanket that covered approximately half of the sensor hood. The heater was located on the underside of the hood.

3.2.1.1.2 Full-Size Heating Element.

This refers to a heater in the form of a blanket covering the entire hood on the Look-Out configuration and covering the entire hood except for the flange area (figure 3) on the Look-Down configuration and the edge of the Look-Out configuration. The heater was located on the underside of the hood.

3.2.1.1.3 End-Loaded Heating Element.

This refers to a full-size heating element that was designed to output more heat on the blanket portions furthest away from the sensor window.

3.2.2 VS SIE Software.

Various modifications were made to the VS SIE software throughout testing. Modifications ranged from the use of different gain values to the addition of algorithms designed to aid the sensor in compensating for the effects of precipitation on the window. Tables 2 through 5 detail the software versions and RVR components used for the identified testing periods.

[2]Although the addition of a bird spike (ref. figure 3) was incorporated in the design of the Look-Down VS, it was not used in the CRREL test.

TABLE 2. SOFTWARE VERSION-TEST PERIOD: 7/19-7/26 1993

COMPONENT	SOFTWARE VERSION
Maintenance Processing Unit	0706936025
Product Processing Unit A	0701935023
Product Processing Unit B	0701935023
Visibility Sensor 01	2.3B 7/14/93[3]
Ambient Lighting Sensor	2.3B 7/14/93[2]

TABLE 3. SOFTWARE VERSION-TEST PERIOD: 8/2-8/6 1993

COMPONENT	SOFTWARE VERSION
Maintenance Processing Unit	0706936025
Product Processing Unit A	0701935023
Product Processing Unit B	0701935023
Visibility Sensor 01	2.3C 7/30/93[2]
Ambient Lighting Sensor	2.3B 7/30/93[2]

TABLE 4. SOFTWARE VERSION-TEST PERIOD: 8/5-8/6 1993

COMPONENT	SOFTWARE VERSION
Maintenance Processing Unit	0802936026
Product Processing Unit A	0802935024
Product Processing Unit B	0802935024
Visibility Sensor 01 Look-Down configuration	---[4]
Ambient Lighting Sensor	not installed

[3]Erasable Programmable Read Only Memory (EPROM) used for VS and ALS SIE were nonproduction versions and did not undergo factory Software Qualification Tests.

[4]Software for the Look-Down VS was an engineering release. No version number was obtained.

TABLE 5. SOFTWARE VERSION-TEST PERIOD: 8/16-8/26 1993

COMPONENT	SOFTWARE VERSION
Maintenance Processing Unit	0802936026
Product Processing Unit A	0802935024
Product Processing Unit B	0802935024
Visibility Sensor 01 Look-Down configuration	0811932024
Visibility Sensor 02 Look-Out Configuration	0811932024
Ambient Lighting Sensor	0604933023

In previous testing, RVR system alarms occurring during data collection caused the loss and/or misrepresentation of data. For tests described herein, all alarm limits were disabled before testing. Parameters that would have normally caused alarms and/or sensor shutdown are noted in the report.

3.3 INTERFACES.

With the exception of the External User (EU) and Maintenance Data Terminal (MDT), no interfaces were required for testing. The EU interface was used to export sensor data such as extinction coefficient, window contamination, etc., to a data collection computer. The MDT interface was used to monitor RVR system and sensor parameters such as heater status, window signal readings, etc., during testing.

4. TEST AND EVALUATION DESCRIPTION.

4.1 TEST SCHEDULE AND LOCATIONS.

Testing was performed at CRREL in Hanover, New Hampshire, during the following periods: July 19 through 23, 1993; August 3 through 6, 1993; and August 17 through 26, 1993.

4.2 PARTICIPANTS.

Personnel from the following organizations conducted and supported CRREL testing:

Organization	Role
ACT-320	Test Director/Testing
ANN-400	Test Planning and Observation
AOS-220	Test Engineering/Testing
VNTSC	Test Planning/Engineering/Testing
CRREL	Laboratory Resource Support
Teledyne Controls Inc.	Test Engineering/Testing

4.3 LABORATORIES AND EQUIPMENT.

Two separate laboratories were used for CRREL testing: the "Navy" Chamber and the "ROWPU" Chamber.

4.3.1 Navy Chamber.

The Navy Chamber is a 12' x 12' x 9' (L x W x H) laboratory equipped with a ceiling light and two collocated fans. The fans, which were located just below the ceiling, were part of the air conditioning system used to maintain the required room temperature. Although the Navy Chamber was capable of reaching temperatures as low as -40° F, RVR tests discussed here included temperatures no less than -20° F. The Navy Chamber was used during the first two test periods.

4.3.2 ROWPU Chamber.

The ROWPU Chamber is a 44' x 28' x 15' (L x W x H) laboratory equipped with wall lights and ceiling fans. The size of the ROWPU Chamber permitted tests involving wind tunnels and fog generation equipment to be easily conducted. This room was used to reach temperatures as low as -20° F during testing. The ROWPU Chamber was used during the last test period.

4.3.3 Laboratory Equipment.

Equipment described in the following subparagraphs was used to simulate various weather phenomenon during CRREL tests.

4.3.3.1 Wind Tunnels.

A squirrel cage fan fastened to a duct was used to simulate wind in the ROWPU Chamber. This assembly will be referred to as a "wind tunnel" for the remainder of the report. There were two types of ducts used during testing. The first was cylindrical with dimensions of 4.6' x 2.5' (L x D, figure 4). The second was rectangular with dimensions of 5' x 2.5' x 4' (L x H x W, figure 5). The rectangular wind tunnel was tapered at the discharge end to produce a more uniform wind.

4.3.3.2 Fog Generation.

Various equipment and methods were used to produce man-made fog. Most were not successful enough for testing purposes. The most effective device was a high-powered spray nozzle in conjunction with a steam generator.

4.3.3.3 Precipitation Generation Devices.

Several devices were used to simulate precipitation events. Each device was used independently or in conjunction with the wind tunnel to propel different types of snow at the VS.

4.3.3.3.1 Spray Mister.

Portions of the CRREL tests used a hose attached to a spray nozzle to simulate "wet snow" weather conditions. Wet snow refers to snow with a high water content. The device was referred to as the spray mister and output tiny droplets of water atomized by pressurized air. Laboratory chamber temperatures froze the water droplets before reaching the VS.

4.3.3.3.2 Sawdust Blower and Hose.

The combination of a sawdust blower and hose was used to simulate most snow events during testing. The sawdust blower was positioned to breakdown and propel man-made snow in front of the wind tunnel or directly at the VS during test scenarios. Hose diameters ranging from 1" to 4" were used to produce wind speeds ranging from 25 to 11 miles per hour (mph), respectively.

4.3.3.3.3 Snow Gun.

The snow gun was a high-powered spray nozzle device consisting of a wide barrel and pistol grip that could output large quantities of wet snow over distances ranging from 10 to 15 feet.

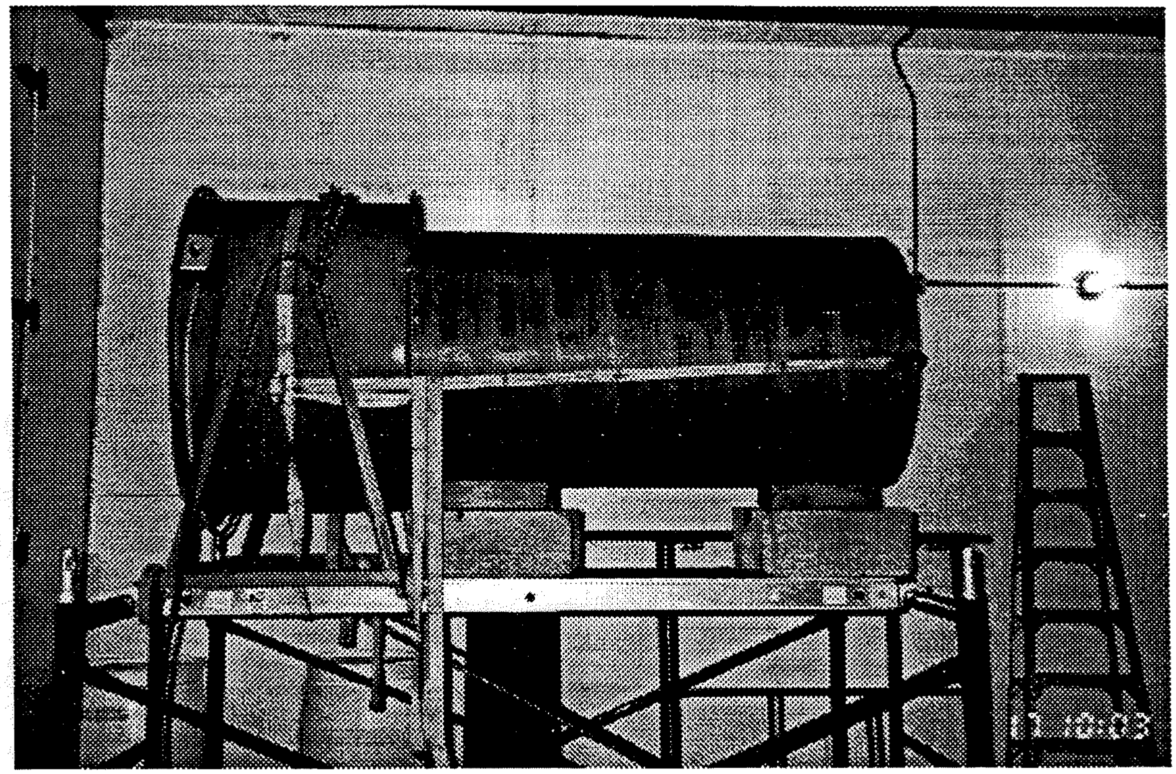

FIGURE 4. CYLINDRICAL WIND TUNNEL

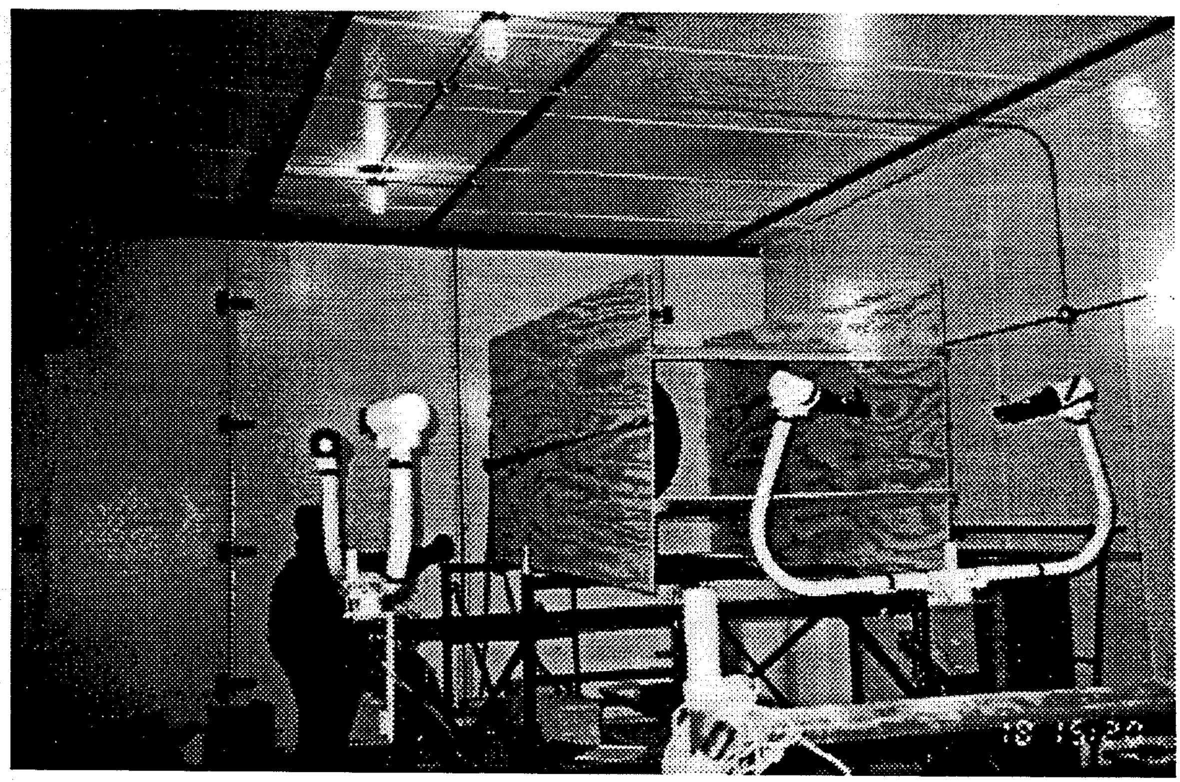

FIGURE 5. RECTANGULAR WIND TUNNEL WITH LKDWN VS

4.4 TEST OBJECTIVES.

The primary objectives of CRREL testing were to assess the effectiveness of sensor modifications in preventing system malfunctions during blowing precipitation and low visibility conditions. Testing was also used to better understand known problems such as snow clogging and icing of the VS. Test objectives and criteria for each test are stated in section 5 where test procedures are described individually.

4.5 TEST DESCRIPTIONS.

Tests conducted at CRREL can essentially be broken down into six categories. The categories are discussed further in subsequent sections of the report and are identified as follows:

a. Volume Density Baseline Determination;

b. Direction-Based Extinction Coefficient Measurement;

c. Window Contamination and Clogging;

d. Tx and Rx Temperature Difference (TX RX Temp Diff) Measurement;

e. De-Ice Heater Control Performance; and

f. Low-Visibility Performance.

4.5.1 Volume Density Baseline Determination.

Volume Density Baseline Determination was used for two main purposes: to attempt to relate test conditions to actual weather extinction coefficients, and to establish benchmarks for ensuring continuity in subsequent blowing snow tests. Volume density values, measured in inverse kilometers (km^{-1}), refer to the VS extinction coefficient for a given snow rate measured in ounces per minute (oz/min.).

Two versions of this test were performed. Different wind tunnels, snow rates, and chamber temperatures were used for each. An equipment change allowed a more reliable volume density baseline to be established in version 2.

Refer to paragraph 5.1 for specifics concerning Volume Density Baseline Determination test conduct.

4.5.2 Direction-Based Extinction Coefficient Measurement.

During execution of volume density baseline tests, it was noted that the direction of precipitation traveling into the VS scatter volume (figure 3) appeared to have a significant effect on the extinction coefficient measurement. This test sought to confirm and quantify this relationship.

The test consisted of two parts in which blowing snow was directed into the VS scatter volume. Each part of the test was the same except for the direction at which the blowing snow entered the VS scatter volume. The extinction coefficient readings for each part were compared during post-test analysis.

Refer to paragraph 5.2 for specifics concerning Direction-Based Extinction Coefficient Measurement.

4.5.3 Window Contamination and Clogging.

The Window Contamination and Clogging tests were created to assess sensor modifications. The modifications were intended to address high window signals resulting from precipitation striking the VS window and VS snow clogging/icing. The simulated weather conditions included freezing mist and blowing snow. In addition, data from these tests were used to determine how much window contamination signal loss occurred with precipitation on the VS window.

4.5.3.1 Spray Mist Tests.

As discussed in paragraph 4.3.3.3.1, a spray mister was used to simulate wet snow conditions during testing. Four versions of the spray mist test were conducted. Their differences can be summarized as follows:

a. Versions 1 and 2 were conducted at slightly different chamber temperatures;

b. Version 3 used the wind tunnel for additional cooling effects; and

c. Version 4 used a snow gun to provide a maximum mist volume output.

4.5.3.2 Blowing Snow Tests.

The remaining Window Contamination and Clogging tests were simulations of various blowing snow events. These simulated snow events used different types of man-made snow, wind tunnels, snow directions, snow rates, snow blowers, and chamber laboratories to create a variety of snow conditions. Specifics for each aforementioned item are described in the following subparagraphs.

4.5.3.2.1 Man-Made Snow.

Three types of man-made snow were used in these tests. They are described as follows:

a. Hoar-frost produced by freezing a large pool of water and collecting the ice particles from the top surface;

b. Artificial snow, created before testing and kept in storage; and

c. Snow generated real-time from a snow gun.

4.5.3.2.2 Wind Tunnel Type.

The cylindrical wind tunnel (figure 4) was used for initial tests, but it was discovered that the rectangular wind tunnel (figure 5) provided a more evenly distributed and homogeneous snow output. The snow output using the cylindrical wind tunnel was often unevenly distributed and not as efficient, i.e., amount of snow output as compared to input. For these reasons, later tests utilized the rectangular wind tunnel.

4.5.3.2.3 Direction of Snow Spray.

For most tests, snow was directed parallel to the floor and from a single direction. However, to determine whether the sensor was susceptible to high window signals and clogging from other directions, various azimuth and elevation angles, e.g., Angular Blowing Snow Test, were used during testing. See blowing snow tests in section 5.3.

4.5.3.2.4 Snow Rate.

For most blowing snow tests, snow was manually fed into a sawdust blower, which blew snow particles between the wind tunnel and VS. The snow rate refers to the amount of snow measured in oz./min., that was manually input to the sawdust blower before being propelled by the wind tunnel.

The snow rate was selected to match benchmarked values determined in Volume Density Tests 1 and 2. Except where noted, each blowing snow test used the same snow rate.

4.5.3.2.5 Snow Blower Type.

Three types of snow blower apparatus were used during testing. The most frequently used apparatus consisted of a sawdust blower with an attached hose, and a wind tunnel. The sawdust blower was used to propel snow in front of the wind-tunnel which, in turn redirected the snow to the VS Tx or Rx.

Other tests used a high-powered snow gun to release high water content snow toward the sensor.

Finally, tests not requiring large chambers used only the sawdust blower with an attached hose to propel snow directly at the sensor. Various hose diameters were used to create different wind speeds and snow density.

4.5.3.2.6 Chamber Laboratory.

Due to the small amount of space needed, blowing snow and spray mist tests performed without the wind tunnel were conducted in the NAVY Chamber. Conversely, all tests using the wind tunnel and fog generation equipment required additional space and therefore were conducted in the ROWPU Chamber.

4.5.3.2.7 VS Distance From Snow Blower.

The distance and position of the VS in relation to the snow blower was based on the objective and intent of each test. For instance, in the Angular Blowing Snow Test, the fork axis of the VS was placed approximately 3 feet from the snow blower to ensure that the snow hit the VS at all of the desired angles. In the Horizontal and Upward Blowing Snow Tests, a distance of 3.5 feet was chosen to ensure that the snow spray could be easily directed on the VS window. Additionally, since the blowing snow range of the snow gun was further than other devices, the distance between the snow gun and the VS was approximately 6 feet during the High Intensity Blowing Snow Tests. Refer to paragraph 5.3 for specifics concerning Window Contamination and Clogging test conduct.

4.5.4 Tx and Rx Temperature Difference Measurement.

The VS Tx and Rx each have three heaters located on the hood and inside the sensor head. Because the operation of these heaters is controlled from thermocouples located in the Tx, there was concern that under certain weather conditions, icing could occur on the Rx while the Tx was still above ice inducing temperatures.

To help determine if this theory was valid, this test was designed to collect temperature readings[5] for the VS Tx and Rx. The readings were taken during simulated winds where the ambient temperature was near freezing. A significant temperature difference between the Tx and Rx would suggest the design of the heater control circuitry be modified.

Two versions of this test were performed. In version 1, a simulated wind was directed at an angle perpendicular to the sensor fork axis. Temperature readings from the VS Tx and Rx were monitored until a steady-state temperature was achieved. The sensor fork axis was then rotated 22.5° and the test was repeated. The latter part of this sequence was repeated until the fork axis had traversed ∠90°.

Version 2 of this test was essentially the same as version 1 with the exception of not rotating the sensor fork axis after achieving the steady-state temperatures. Additionally, the Look-Out and Look-Down sensor versions were both used to compare temperature profiles of the prototypes.

Refer to paragraph 5.4 for specifics concerning the Tx and Rx Temp Diff. Measurement test conduct.

4.5.5 De-Ice Heater Control Performance.

It was theorized that "dry" snow would not attach to the sensor window or hood if the heaters were not activated. Dry snow refers to precipitation occurring at temperatures significantly below freezing (e.g., less than -10° F). Since the heaters were normally on during cold conditions, this test sought to determine if deactivating heaters during dry snow conditions would increase the sensor resistance to icing/clogging. A snow clogging rate was established for the sensor. The snow-clogging rate was defined as the snow rate (paragraph 4.5.3.2.4) where the de-ice heater (located near the sensor window) is just able to melt off the accumulation of snow on the window.

After determining the snow-clogging rate, the de-ice heater was disabled, and snow was redirected towards the sensor at the same rate. The snow/ice-clogging characteristics of the sensor with and without the de-ice heater were compared.

[5]Temperature readings were obtained from external thermocouples placed on the Tx and Rx hoods. Thermocouples were located approximately 3.5 inches from the outer edge of the hood.

Two versions of this test were performed. The primary difference between versions was the chamber temperature at which the tests were performed. The second version of the test also used the VS calibration plate to collect data indicating the relationship between extinction coefficient loss with precipitation on the VS window.

Refer to paragraph 5.5 for specifics concerning De-Ice Heater Control test conduct.

4.5.6 Low Visibility Performance.

Although it had been shown in theory that the RVR system could accurately measure visibility within the Category IIIb range, no testing had been performed during actual Category IIIb conditions. Low Visibility Performance tests were conducted to determine system performance under simulated conditions. This was accomplished by comparing extinction coefficient readings for the RVR VS and the Optec transmissometer during fog densities which approximated Category IIIb visibility. The Look-Down VS and Look-Out VS were both used in the comparison. The transmissometer was used as the primary reference for comparison.

Significant problems and limitations were encountered in the creation of man-made fog that was not anticipated. For example, attempts to ensure that fog densities about each sensor were the same were extremely difficult because there was no method for "spreading" fog evenly throughout the test chamber. The actual creation of fog was a formidable task, and it is likely that there are differences in the light scattering properties of man-made versus actual fog.

Several versions of tests were performed. The differences in versions can be summarized as follows:

a. Fog Tests 1 through 3 utilized essentially the same setup and configuration. The Look-Down VS was recalibrated in Fog Test 2; and

b. Fog Tests 4 and 5 involved placing sensors in different locations within the chamber to determine fog density variances within the chamber. The intent of these tests was also to reduce the probability of light interference from collocated sensors.

Category IIIb visibility was identified as achieved when the collection of New Generation RVR and transmissometer sensors measured extinction coefficients ranging from 50 km^{-1} to 340 km^{-1}. These extinction coefficient values equated to RVR readings ranging from 100 to 800 feet as measured by the New Generation

RVR[6]. The extinction coefficient values were based on ambient light readings ranging from 700 to 1400 foot-lamberts and a runway light setting 5.

The following procedure was performed for each test:

a. Enough fog was injected in the chamber to surpass the Category IIIb visibility range;

b. Fog was allowed to dissipate naturally until visibility levels increased to the Category IIIb range; and

c. After visibility entered the Category IIIb range, visibility readings for each sensor were recorded[7].

4.5.6.1 Equipment Modifications.

Performing Low Visibility Performance tests entailed some minor modifications to the RVR system and transmissometer.

For instance, since RVR system readings[8] were required for these tests, an ALS was added to the configuration. Runway Light Intensity Monitor (RLIM) values were entered manually to the DPU via the MDT interface.

The Optec transmissometer is normally used to measure visibility above the Category IIIb range. To allow the transmissometer to make short range visibility measurements, the baseline or distance between the transmissometer Tx and Rx was reduced. The resultant baseline was 20 feet.

Refer to paragraph 5.6 for specifics concerning Low Visibility Performance test conduct.

4.6 DATA COLLECTION AND ANALYSIS METHOD.

Log files, video cameras, and infrared cameras were used to record test data. Log files recorded data from the RVR DPU and EU ports. These files permitted the test team to review RVR performance after each test. Video and infrared cameras were used to allow the test team to monitor testing from inside or outside of the laboratory chamber in real time. In addition to monitoring testing, video cameras were also used to review test results. Infrared cameras were used to examine the temperature profile of the VS during Window Contamination and Clogging tests.

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[6]Category IIIb visibility range is defined from 150 to 750 feet.

[7]To continue testing for longer durations, it was necessary to reinject fog in the chamber periodically.

[8]RVR system readings in this context refer to the inclusion of the ALS and RLIM as opposed to a visibility reading from only the VS.

5. TEST CONDUCT.

5.1 VOLUME DENSITY BASELINE DETERMINATION.

As described in paragraph 4.5.1, Volume Density Baseline tests were used to establish benchmarks for conducting the blowing snow tests. Snow rates were mapped to a target extinction coefficient range as measured by the VS. The target range for the extinction coefficients was approximately 5 to 40 km^{-1} given ambient light levels of approximately 1.5 foot-lamberts and a runway light setting of 5.

5.1.1 Volume Density Test 1.

Volume Density Test 1 was conducted on August 17, 1993, using the cylindrical wind tunnel in the ROWPU Chamber. The test equipment was set up as shown in figure 6. In this figure, the Look-Down VS and Look-Out VS are designated as LKDWN VS and LKOUT VS, repectively. Other test parameters included the following:

a. Chamber temperature of -7.46° F;

b. Wind tunnel air speed measured at 20 mph;

c. Artificial snow, previously generated and stored frozen; and

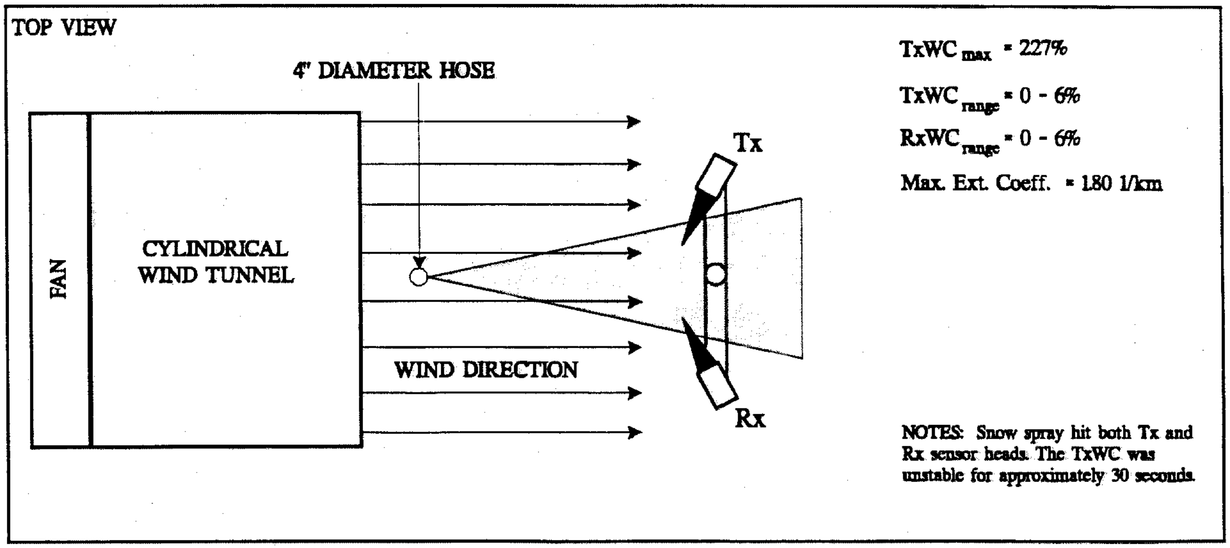
d. Snow rate of 48 oz. per minute.

5.1.1.1 Results.

The maximum extinction coefficient achieved during testing was 1.8 km^{-1}. The snow volume was inconsistent, and more snow hit the Tx and Rx components of the sensor than was desired. Snow also hit the sensor window and created contamination signal levels that were undesirable for this test.

5.1.1.2 Conclusion/Comments.

Since the snow rate produced extinction coefficient readings below the desired range and snow that hit the Tx and Rx windows, this rate was considered insufficient for subsequent blowing snow tests.



WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test time

Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 48 oz. per minute

Room Temp Test 1 = -7.46° F

Wind Speed = 20-22 mph

NOTE: All window contaminations are in .5% units

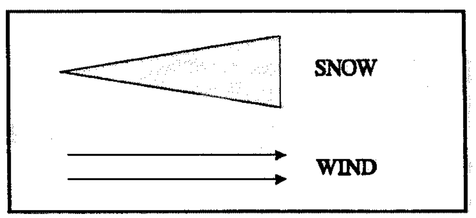


FIGURE 6. LKDWN VS VOLUME DENSITY TEST 1 - LOCATION: ROWPU CHAMBER

The design of the wind tunnel was determined to be primarily the cause of the aforementioned problems. The data from this test was not considered reliable.

5.1.2 Volume Density Test 2.

Volume Density Test 2 was conducted on August 17, 1993, using the rectangular wind tunnel in the ROWPU Chamber. The test equipment was as shown in figure 7. Other test parameters included the following:

a. Chamber temperature of 20° F;

b. Wind tunnel air speed measured at 20 mph;

c. Artificial snow, previously generated and stored frozen; and

d. Snow rate of 16 oz. per minute.

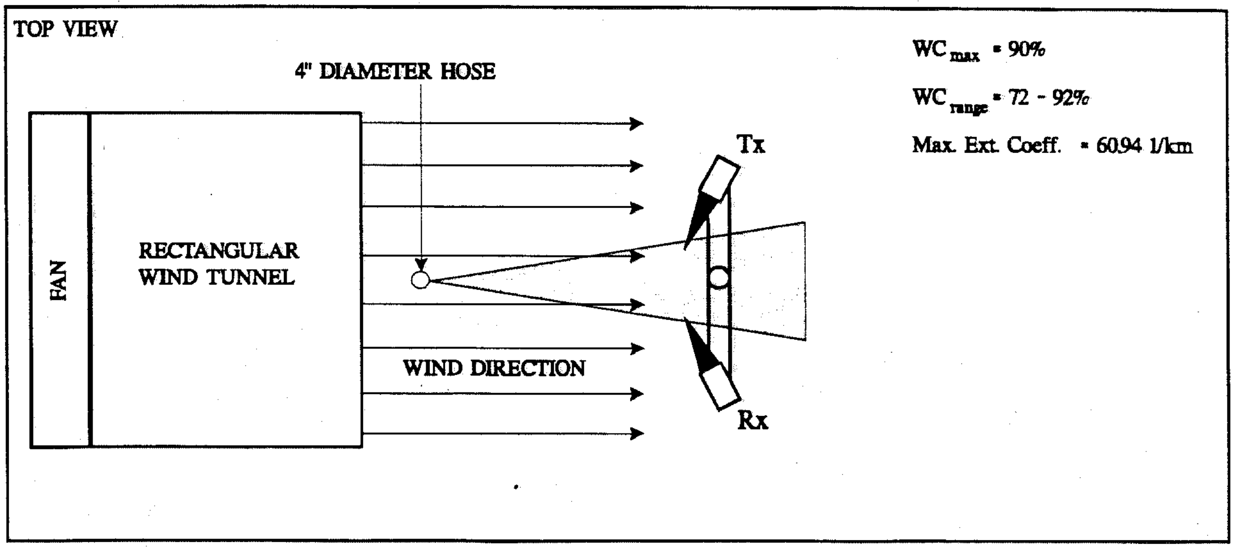
5.1.2.1 Results.

Although the maximum extinction coefficient of 60.94 km^{-1} was beyond the target range, most of the readings were within the desired range. There was a noted improvement in the accuracy in which the blowing snow was directed. Also, due to the increased efficiency and more uniform wind produced with the rectangular wind tunnel, the snow rate was decreased to 16 oz./min.

Despite the fact that less snow was observed striking sensor components, high Tx and Rx window signals were still noted with maximum readings between 72 percent and 92 percent. This was significantly less than in the previous test; however, it appeared that the VS was too sensitive to precipitation striking the sensor lenses.

5.1.2.2 Conclusion/Comments.

With allowances for the detected window contamination, the volume density achieved with a snow rate of 16 oz/min. was considered representative of an actual snow event.



WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp Test 1 = -7.46 °F

Wind Speed = 20-22 mph

NOTE: All window contaminations are in .5% units

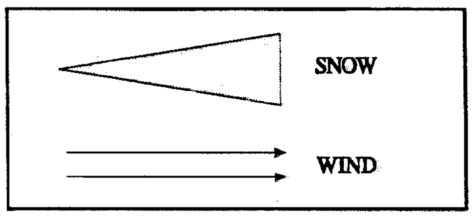


FIGURE 7. LKDWN VS VOLUME DENSITY TEST 2 - LOCATION: ROWPU CHAMBER

5.2 DIRECTION-BASED EXTINCTION COEFFICIENT MEASUREMENT.

As described in paragraph 4.5.2, the test was intended to determine if the direction of blowing snow was related to the measured extinction coefficients. The test consisted of two parts. Part 1 measured extinction coefficients of the Look-Down VS with the fork axis perpendicular to the snow direction, e.g., $\angle 0°$. Part 2 measured the volume density of the Look-Down VS at the opposite angle, e.g., $\angle 180°$.

5.2.1 Direction-Based Extinction Coefficient Test.

The Direction-Based Extinction Coefficient Test was conducted on August 23, 1993, using the rectangular wind tunnel in the ROWPU Chamber. Test equipment was as shown in figure 8. Other test parameters included the following:

a. Chamber temperature of 20° F;

b. Wind tunnel air speed measured at 20 mph;

c. Artificial snow, previously generated and stored frozen; and

d. Snow rate of 48 oz. per minute.

5.2.1.1 Results.

The maximum extinction coefficient readings at $\angle 0°$ were 650 km^{-1}, and 325 km^{-1} at $\angle 180°$. Additionally, it was noted that at 0°, the window signals reached a maximum of 88 percent, and at 180°, reached only 20 percent.

5.2.1.2 Conclusion/Comments.

This result suggests that the direction the snow is moving through the sensor scatter volume can significantly affect the extinction coefficient measurement. However, due to the large extinction coefficient measurements; i.e., 650 km^{-1} and 325 km^{-1} both translate to RVR readings less than 100 feet with the ambient and runway light settings used during testing, observed in both tests, the impact on more typical RVR readings is not clear.

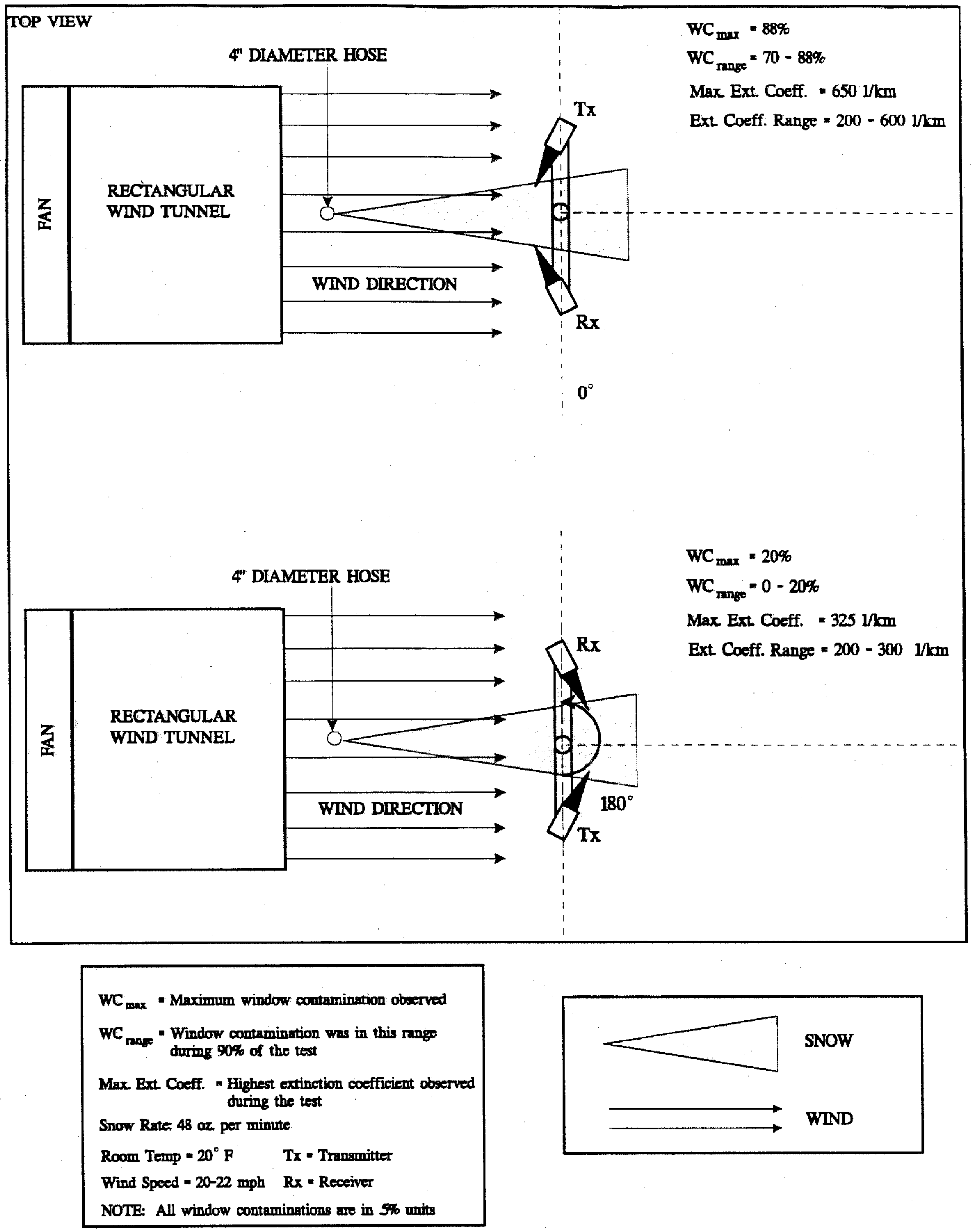


FIGURE 8. DIRECTION-BASED EXTINCTION COEFFICIENT TEST

Additional testing at lower snow rates should determine the following:

a. If these results occur consistently during extinction coefficient levels representative of actual snow events; and

b. The degree of accuracy degradation under these circumstances.

5.3 WINDOW CONTAMINATION AND CLOGGING.

These tests consisted of simulations of blowing snow and mist. As mentioned in paragraph 4.5.3, testing was intended to provide data for studying high window signals resulting from precipitation and clogging/icing. To reduce test execution difficulties, the VS Tx and Rx heads were mounted and tested independently in most scenarios.

After each blowing snow or mist test, VS windows were examined. If ice, snow, or any debris remained on the windows, or if VS window signal readings were not near zero, the windows were cleaned before the next test was executed. This ensured conditions caused by one test did not affect the VS performance in a subsequent test.

Most of the Window Contamination and Clogging tests produced window signals that were above the normal operating limits of the RVR sensor. Actual precipitation events with comparable winds, temperatures, etc., would most likely cause alarms and possibly automatic failure of the sensor data.

5.3.1 Spray Mist Test 1.

Spray Mist Test 1 was conducted on the Look-Down VS Rx on August 5, 1993, in the Navy Chamber. The intent of this test was to observe sensor performance during freezing mist conditions for an extended period of approximately 1 hour. The test equipment was set up as shown in figure 9. The chamber temperature was -8° F at the start of the test.

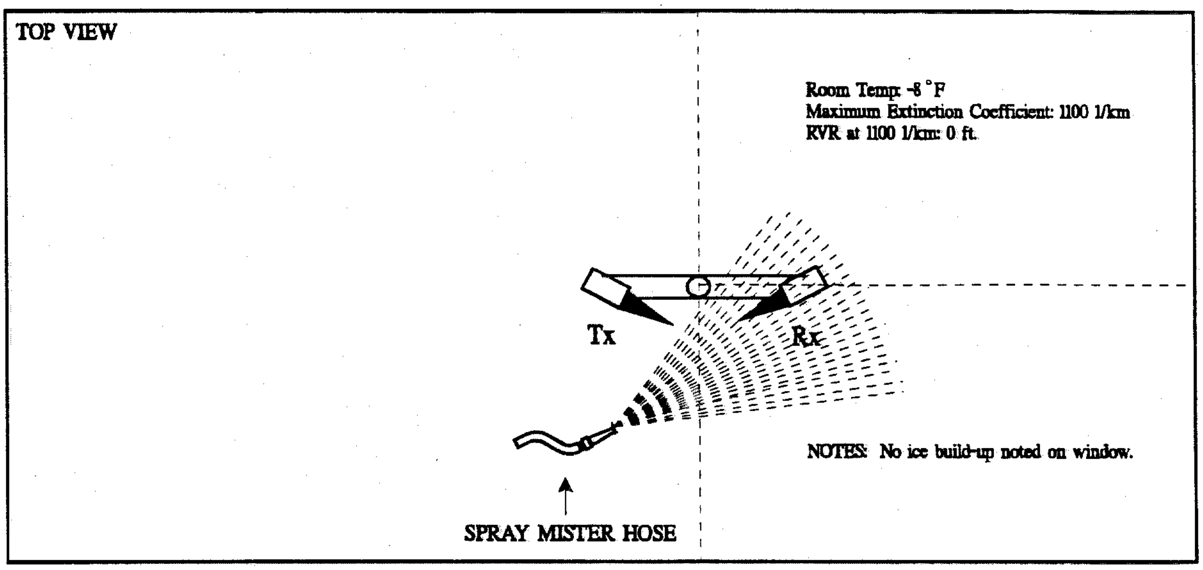


FIGURE 9. SPRAY MIST TEST - LOCATION: ROWPU CHAMBER

5.3.1.1 Results.

The test was stopped numerous times due to clogging of the spray mister device. For periods which the spray mister device was functioning (the longest period was about 15 minutes), there was no accumulation of ice and/or snow on the VS window. However, extremely high extinction coefficients (i.e., 1100 km^{-1} or maximum extinction coefficient) were observed during testing. These levels occurred within 8 minutes during one test interval.

Testing was also halted due to an apparent mismatch between the DPU and EU port extinction coefficient readings. The mismatch was later attributed to the 1-minute average value output from the DPU, versus the snapshot value from the EU port, which is output every 6 seconds.

5.3.1.2 Conclusion/Comments.

Due to frequent stoppages during the test, the test objective was not fulfilled. Nevertheless, the lack of ice buildup on the VS window was a noted improvement from the Look-Out configuration. In previous spray mister tests, the Look-Out configuration experienced ice buildup on the window. This test also suggests that extremely high extinction coefficient readings might quickly occur (maximum extinction coefficients reached within 8 minutes of test) when precipitation is in the form of a mist.

5.3.2 Spray Mist Test 2.

Spray Mist Test 2 was conducted on the Look-Down VS Tx on August 6, 1993, in the Navy Chamber. A refitted spray mister device intended to be more clog resistant was used. The test equipment was set up as shown in figure 10. The test was essentially a repeat of the previous test with the intent of achieving a longer testing duration. The chamber temperature was -18° F at the start of the test.

5.3.2.1 Results.

As in the previous test, there were many stoppages due to clogging of the spray mist device. In addition, some ice buildup was noted on the VS hood.

5.3.2.2 Conclusion/Comments.

The test objective was not fulfilled and a repeat of the test was required.

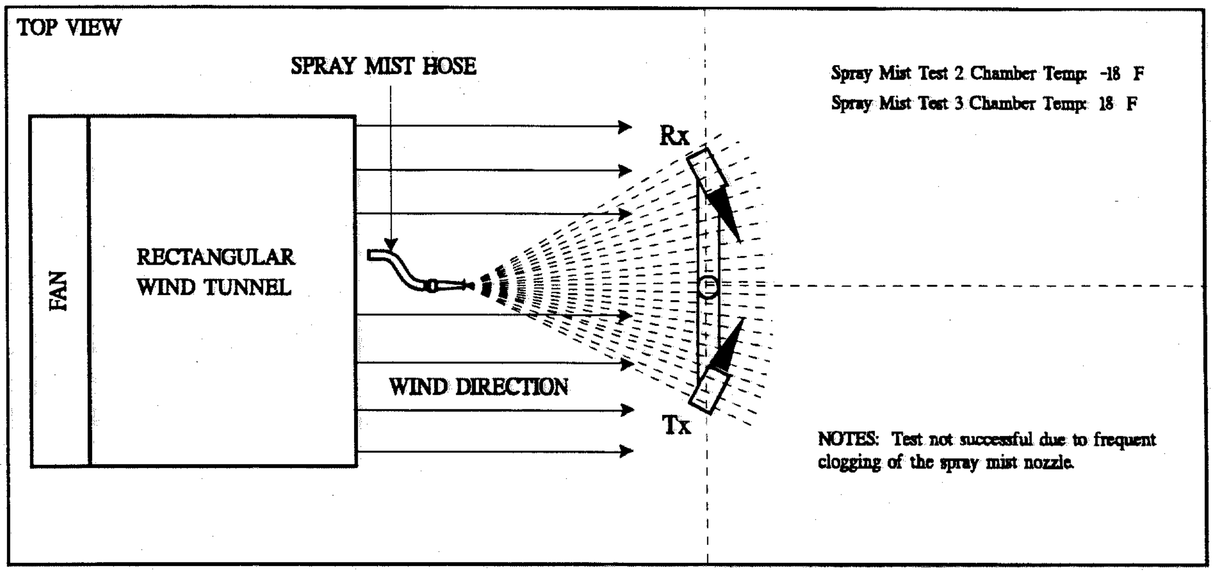


FIGURE 10. SPRAY MIST TEST - LOCATION: ROWPU CHAMBER

5.3.3 Spray Mist Test 3.

Spray Mist Test 3 was conducted on August 19, 1993, in the ROWPU Chamber. This test combined the spray mister device with the wind tunnel to propel frozen mist on both the Look-Down VS Tx and Rx. The wind tunnel air speed was 20 mph. To reduce probability of clogging the spray mister device, the chamber temperature was increased to 18° F. The test equipment was set up as shown in figure 10. The test objective remained as stated in paragraph 5.2.1.

5.3.3.1 Results.

Even though the chamber temperature was significantly warmer than in previous tests, clogging of the spray mist device again prevented successful completion of the test.

5.3.3.2 Conclusion/Comments.

A spray mister device capable of functioning below freezing temperatures is necessary to conduct this test.

5.3.4 Spray Mist Test 4.

Spray Mist Test 4 was performed on August 22, 1993, in the ROWPU Chamber. Because of clogging problems experienced with the spray mister device, a snow gun was used to propel precipitation. As in earlier tests, the mist was directed at the VS Tx.

5.3.4.1 Results.

Testing lasted 11 minutes and produced high window signal readings of 83 percent and extremely high extinction coefficient measurements of 1100 km^{-1}. Water droplets were also observed on the Tx window and an ice conglomerate formed on the edge of the hood (figure 11).

5.3.4.2 Conclusion/Comments.

The Look-Down VS has a heater blanket designed to prevent snow and ice from collecting on the inside of the sensor hood. This blanket covers the majority of the hood but leaves the flange area, i.e., outermost portion, unprotected. Testing showed that

FIGURE 11. ICE CONGLOMERATE FORMATION

ice can build up on unprotected areas of the hood. Extending the heater blanket to the flange would help prevent ice and snow from collecting on the flange of the sensor. The issue of whether snow/ice could collect on the other sensor components, i.e., window, hood, etc., was examined further during the blowing snow and De-Ice Heater Control tests.

5.3.5 Horizontal Blowing Snow Test.

The Horizontal Blowing Snow Test was conducted on the Look-Down VS Tx on August 5, 1993, in the Navy Chamber. The intent of this test was to simulate severe blowing snow conditions. A sawdust blower with hose was used as the snow blower apparatus. As the name implies, the hose was positioned parallel to the floor and directly at the VS hood/window. Testing equipment was set up as shown in figure 12. Other test parameters included the following:

a. Chamber temperature of -8° F,
b. Hose diameter of 4 inches,
c. Sawdust blower air speed of 20 mph,
d. Snow rate of 8 oz./minute, and
e. Test duration of 10 minutes.

5.3.5.1 Results.

No ice or snow was observed on the VS window. However, icicles did form at the bottom of the window. Icicles would grow for about 3 minutes before breaking off. The process would then repeat itself. Water droplets were also observed on the VS window. As noted in previous tests, the sensor was susceptible to ice formations on unheated areas of the window and hood. It was not clear whether the ice formations affected the sensor extinction coefficient measurements.

5.3.5.2 Conclusion/Comments.

The location of the ice formations appeared to be away from the sensor beam path, and the effect on extinction coefficient was probably small; however, additional tests are recommended to confirm no performance degradation.

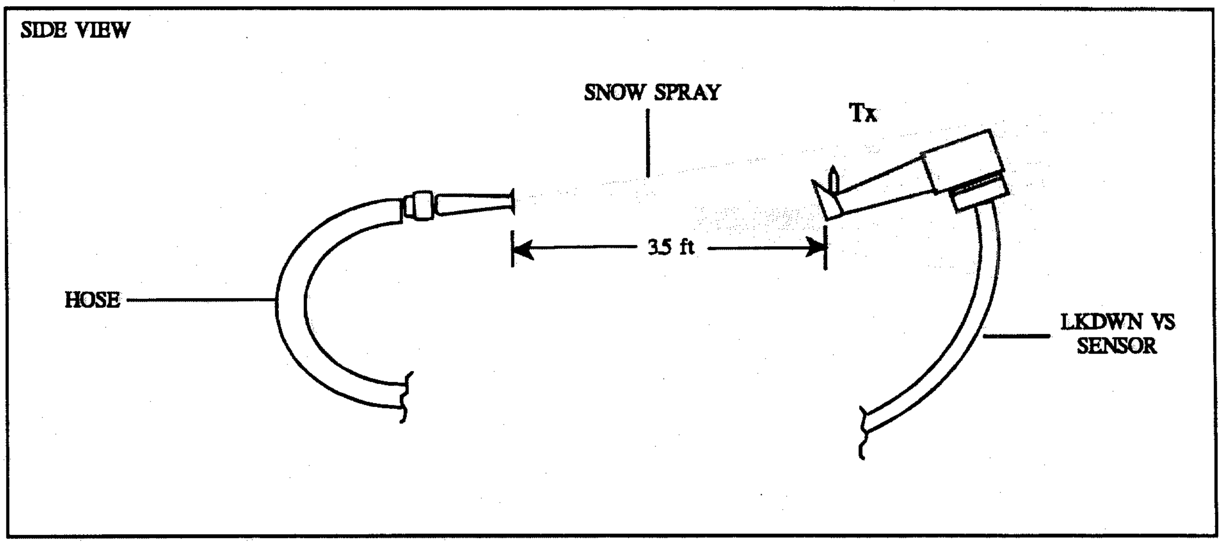


FIGURE 12. HORIZONTAL BLOWING SNOW TEST - LOCATION: NAVY CHAMBER

5.3.6 Upward Blowing Snow Test.

The Upward Blowing Snow Test was conducted on the Look-Down VS Tx on August 5, 1993, in the Navy Chamber. The intent of this test was to determine the limits of sensor resistance to snow/ice-clogging. This was accomplished by simulating a blowing snow event where conditions were similar to a dry snow driven upward by high winds. The sawdust blower with hose was again used for this test. As the name implies, the hose was positioned at an elevated angle, which allowed the snow to hit the VS window and underside of the hood. The test equipment was set up as shown in figure 13. Other test parameters remained as stated in paragraph 5.3.5.

5.3.6.1 Results.

Although a 100 percent clog, i.e., a layer of snow and ice covering the entire area of the sensor window, formed after about 10 minutes, the entire clog fell out of the sensor approximately 15 seconds after the test was completed.

5.3.6.2 Conclusion/Comments.

This result suggests that although the sensor can clog under extremely severe conditions, it can also recover quickly from a clogging state[9].

5.3.7 Upward Blowing Snow with Calibration Plate Test.

The Upward Blowing Snow with Calibration Plate Test was performed on the VS Tx on August 5, 1993, in the Navy Chamber. Although the intent of this test was primarily the same as in paragraph 5.3.6, a secondary goal was to determine the relationship, if any, between the loss in extinction coefficient and precipitation on the VS window. To avoid hitting the calibration plate, the snow direction was altered slightly, impinging the VS window at an angle, as opposed to directly in the previous test. Test equipment was set up as shown in figure 14. Other test parameters remained as stated in paragraph 5.3.5.

[9]Since clogging of the VS window and hood underside can block the light beam path to or from the sensor, unreliable extinction coefficient readings can occur. This could result in higher-than-actual RVR readings.

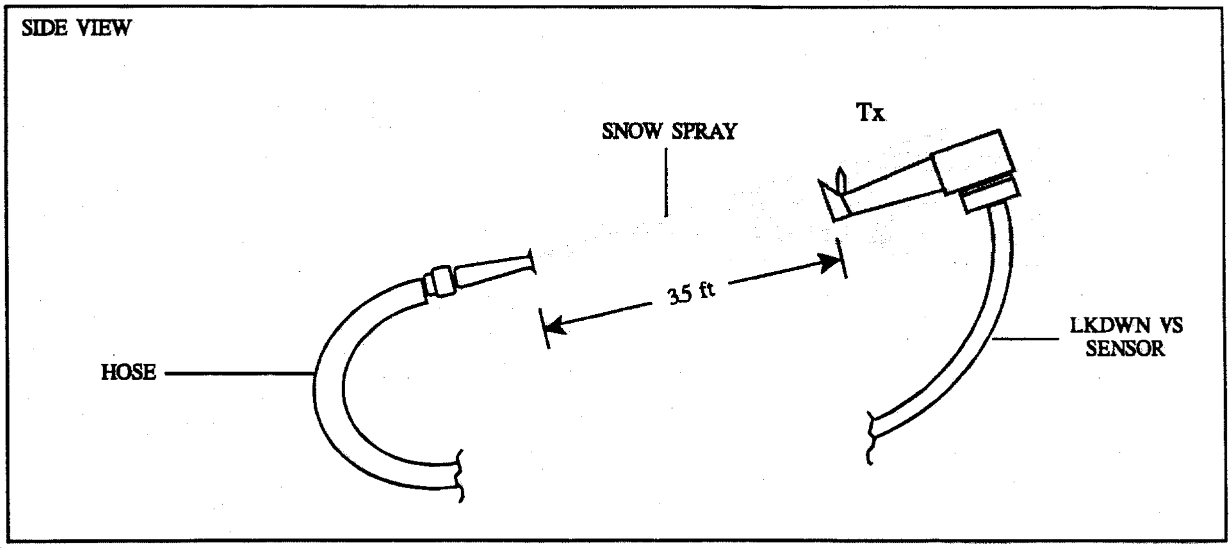


FIGURE 13. UPWARD BLOWING SNOW TEST - LOCATION: NAVY CHAMBER

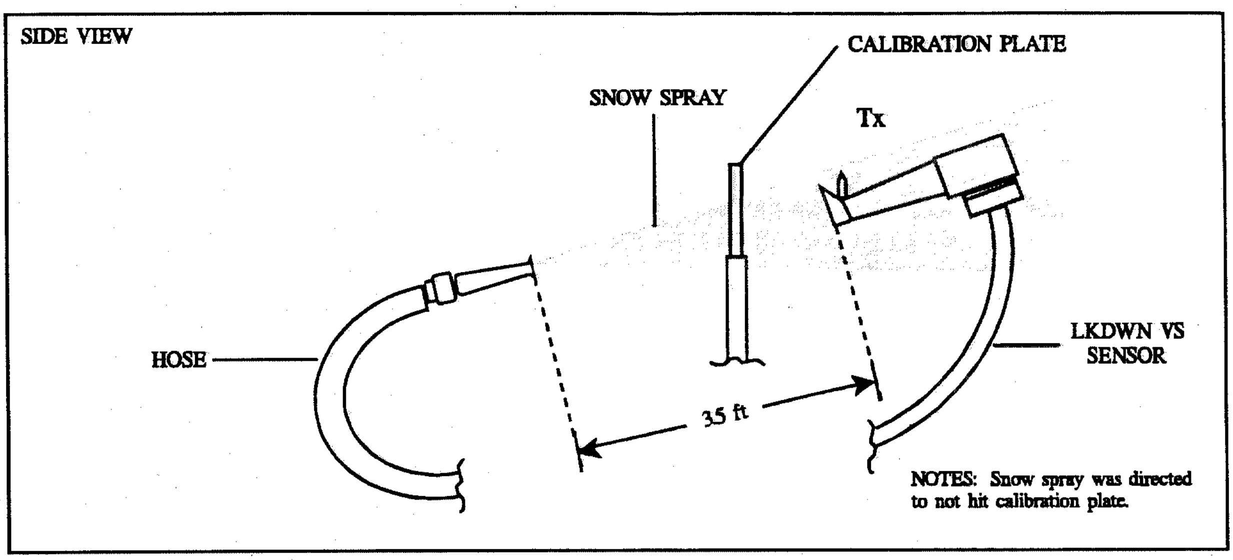


FIGURE 14. UPWARD BLOWING SNOW TEST W/ CALIBRATION PLATE - LOCATION: NAVY CHAMBER

5.3.7.1 Results.

As in the previous test, a 100 percent clog formed on the VS window. However, unlike the previous test, the clog remained for about 5 minutes after the test was completed.

5.3.7.2 Conclusion/Comments.

Although the clog remained for a much longer period of time, the Look-Down configuration clogging characteristics appeared superior to the Look-Out configuration. The characteristics included a quicker recovery time and increased resistance to clogging based on a comparison of test results with the Look-Out configuration VS.

A probable explanation for the extended length of time of the clog is that the design of the hood allows the Look-Down configuration to be more susceptible to precipitation impinging the VS at angles rather than directly in front of the window. A similar relationship was noted during the Angular Blowing Snow Test (paragraph 5.3.8) where higher window signal readings were observed in the Look-Down configuration than in the Look-Out.

5.3.8 Angular Blowing Snow Tests.

The primary objective of these tests was to compare how well the Look-Down VS and Look-Out VS hoods protected their windows from horizontally blowing snow. Snow blown at the rate determined in Volume Density Test 2, was directed at the Tx or Rx of each sensor. Tests were performed for sensor fork angles ranging from 0° to 180° in 22.5° increments. The angles were measured and based on the position of the fork axis and snow direction. Test duration at each angle was approximately 5 minutes.

The Angular Blowing Snow Test was conducted August 18, 1993, in the ROWPU Chamber. Window signal and extinction coefficient readings were monitored for each test. Figures 15 through 41 detail the test scenarios and the following test parameters:

a. Wind tunnel air speed,
b. Chamber room temperature,
c. Position of sensors in relation to wind tunnel,
d. Window signals and extinction coefficient readings,
e. Percentage of VS window clogging, and
f. Sensor visibility readings where noted.

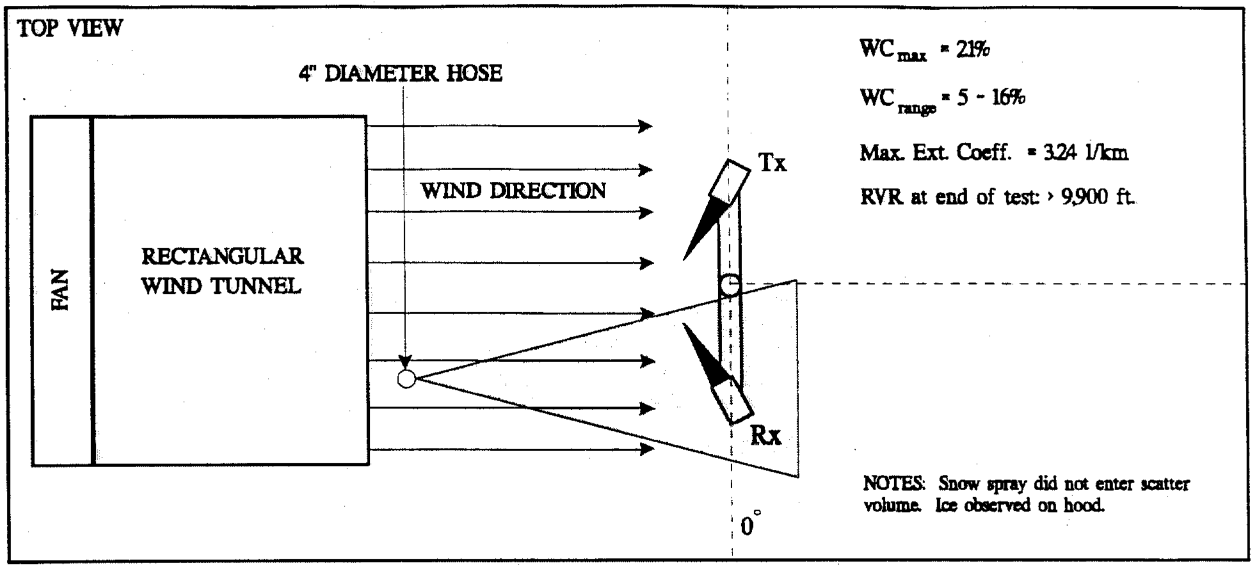


FIGURE 15. LKDWN VS BLOWING SNOW TEST AT 0° (RX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

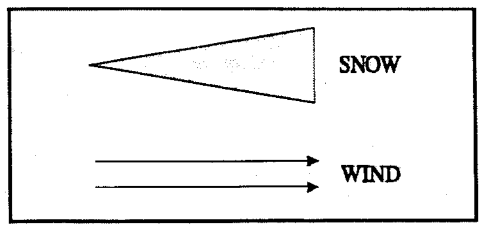
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20 °F Tx = Transmitter

Wind Speed = 20-22 mph Rx = Receiver

NOTE: All window contaminations are in .5% units



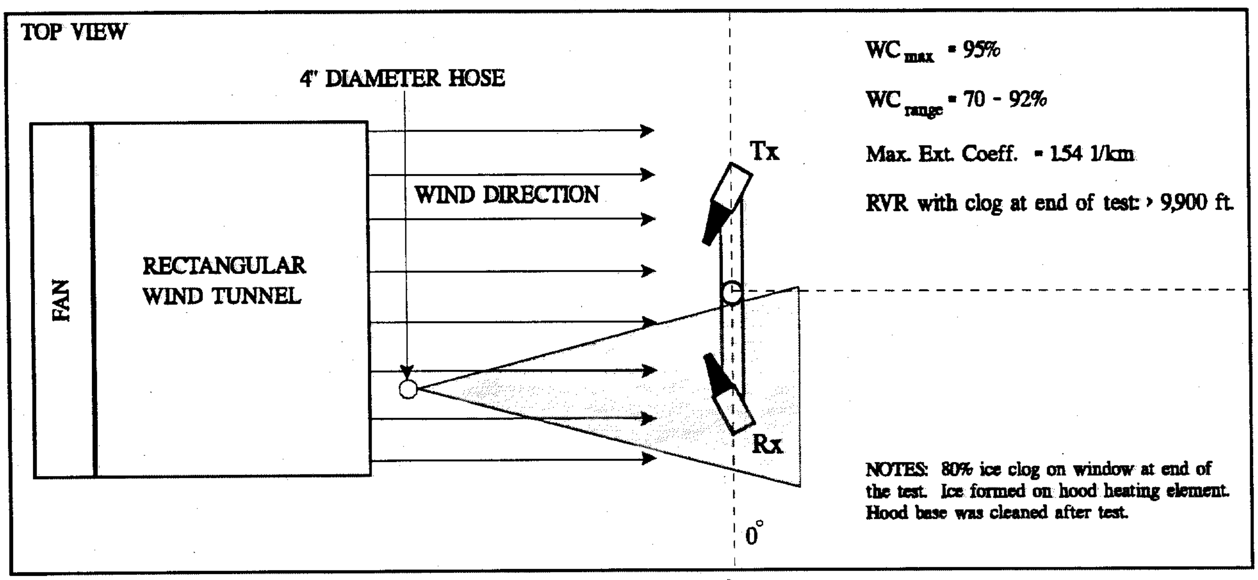


FIGURE 16. LKOUT VS BLOWING SNOW TEST AT 0° (RX) - LOCATION: ROWPU CHAMBER

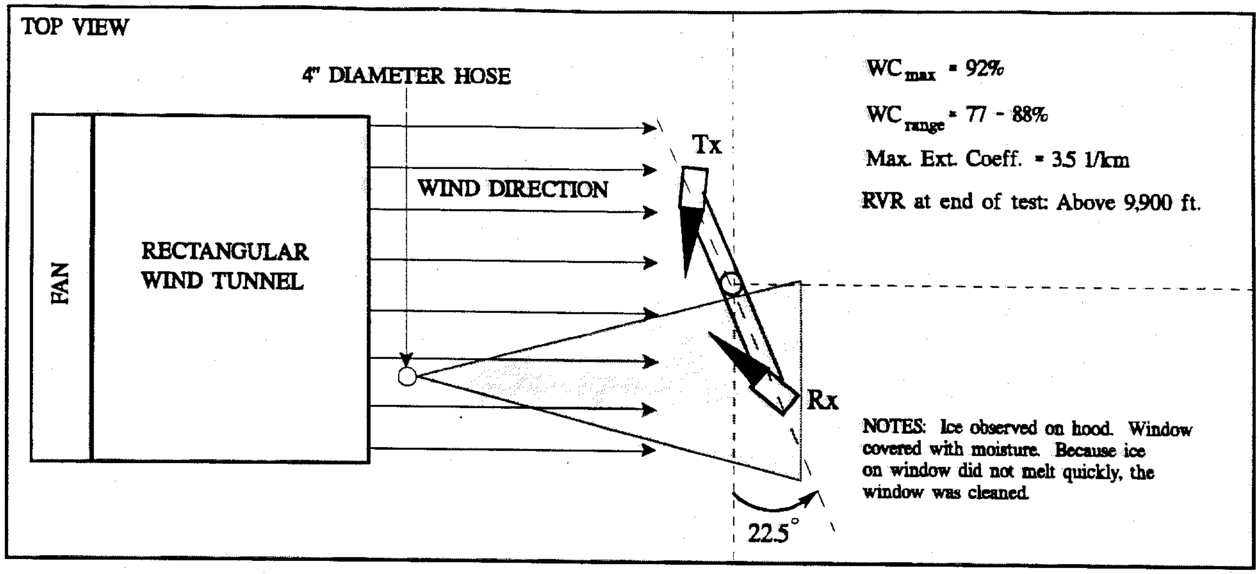


FIGURE 17. LKDWN VS BLOWING SNOW TEST AT 22.5° (RX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

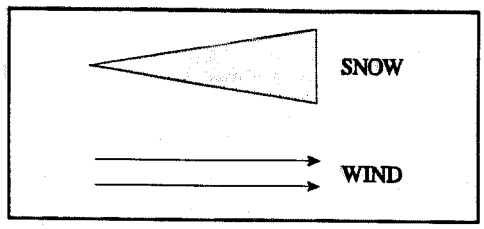
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20 °F Tx = Transmitter

Wind Speed = 20-22 mph Rx = Receiver

NOTE: All window contaminations are in .5% units



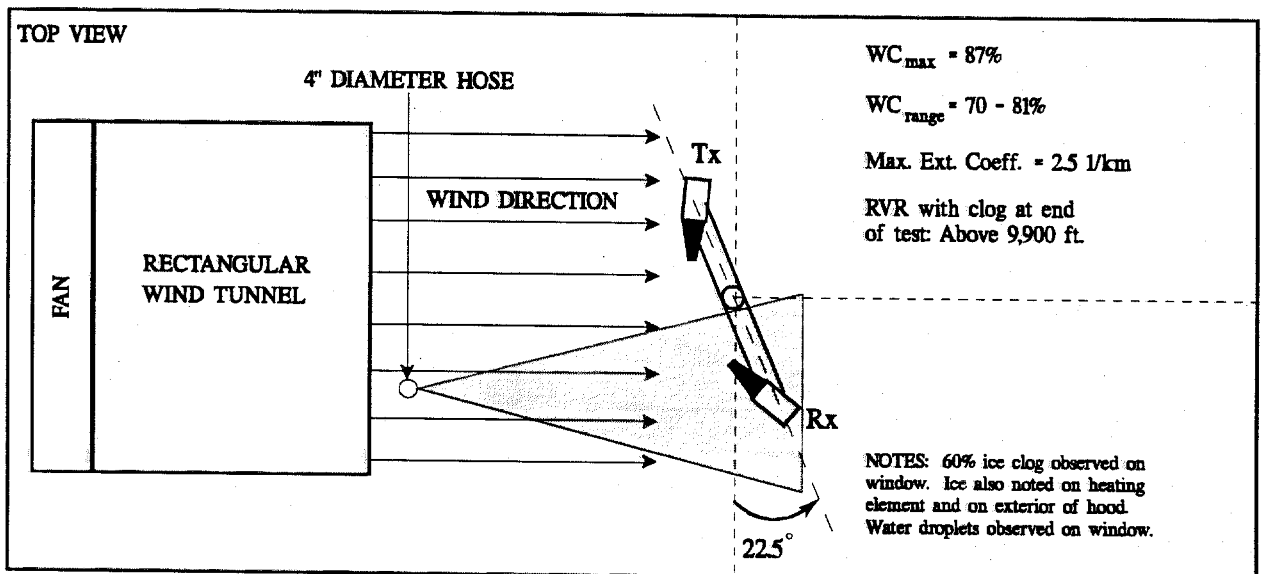


FIGURE 18. LKOUT VS BLOWING SNOW TEST AT 22.5° (RX) - LOCATION: ROWPU CHAMBER

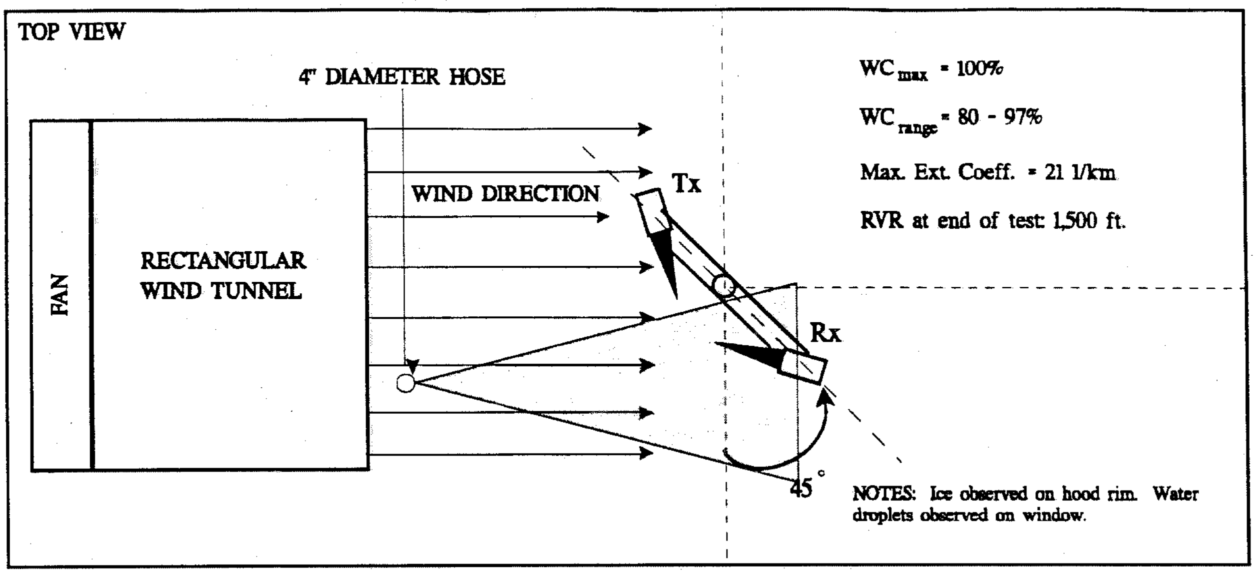


FIGURE 19. LKDWN VS BLOWING SNOW TEST AT 45° (RX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

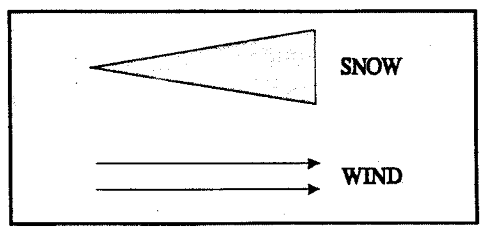
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20 °F Tx = Transmitter

Wind Speed = 20-22 mph Rx = Receiver

NOTE: All window contaminations are in 5% units



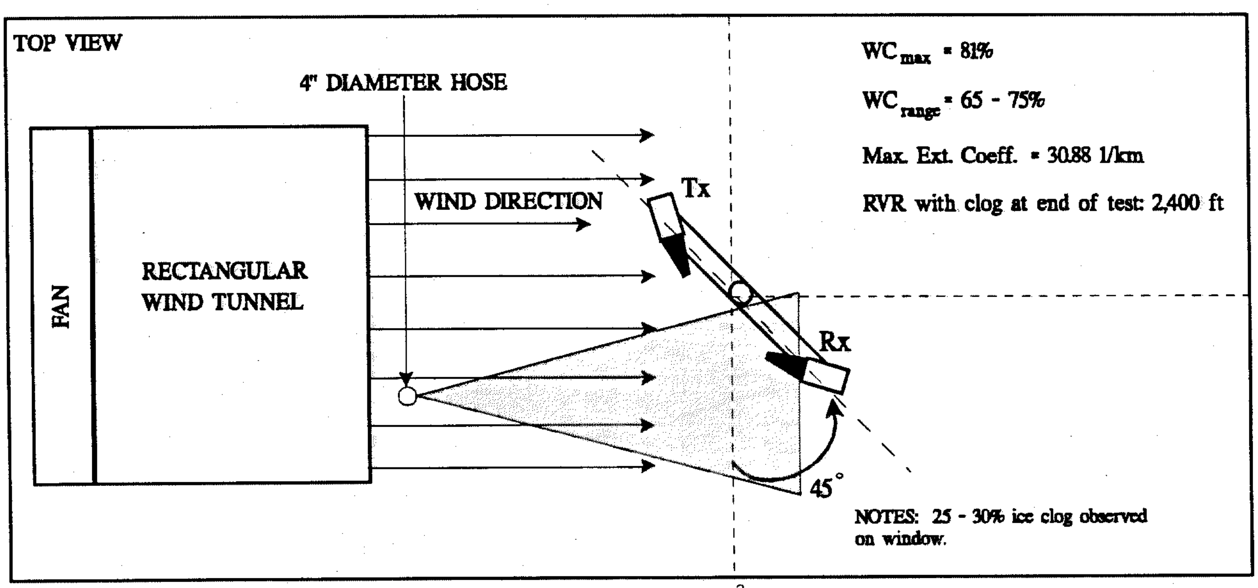


FIGURE 20. LKOUT VS BLOWING SNOW TEST AT 45° (RX) - LOCATION: ROWPU CHAMBER

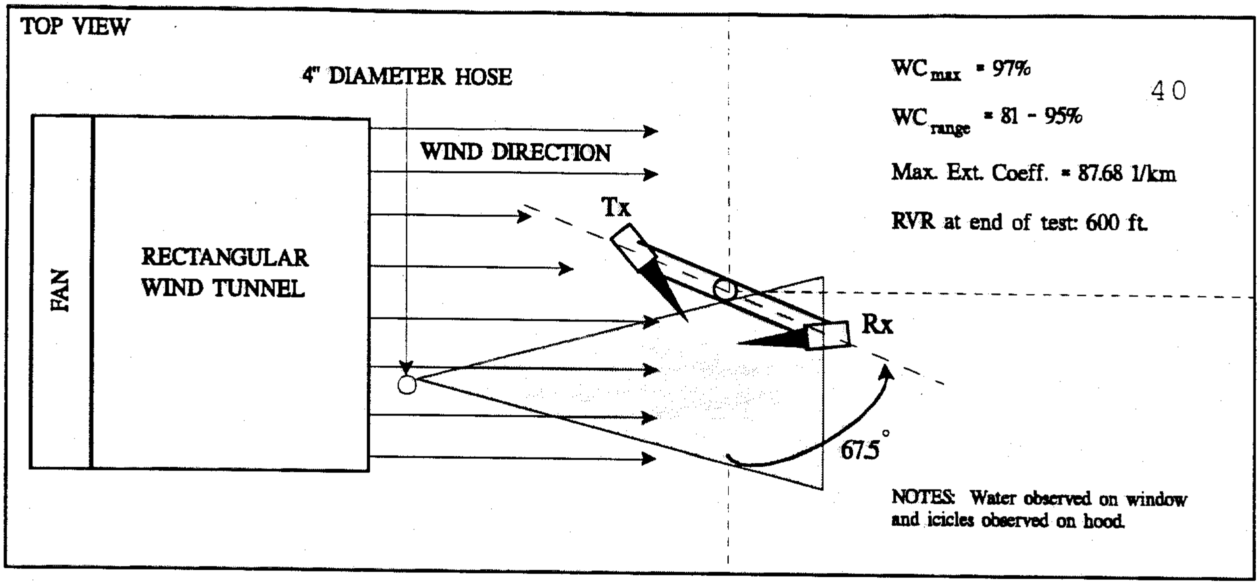


FIGURE 21. LKDWN VS BLOWING SNOW TEST AT 67.5° (RX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

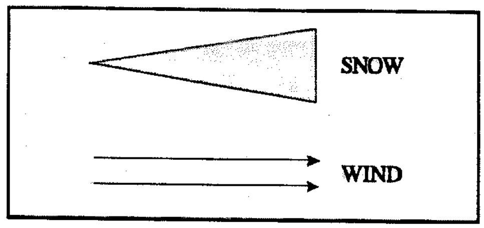
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20 °F Tx = Transmitter

Wind Speed = 20-22 mph Rx = Receiver

NOTE: All window contaminations are in 5% units



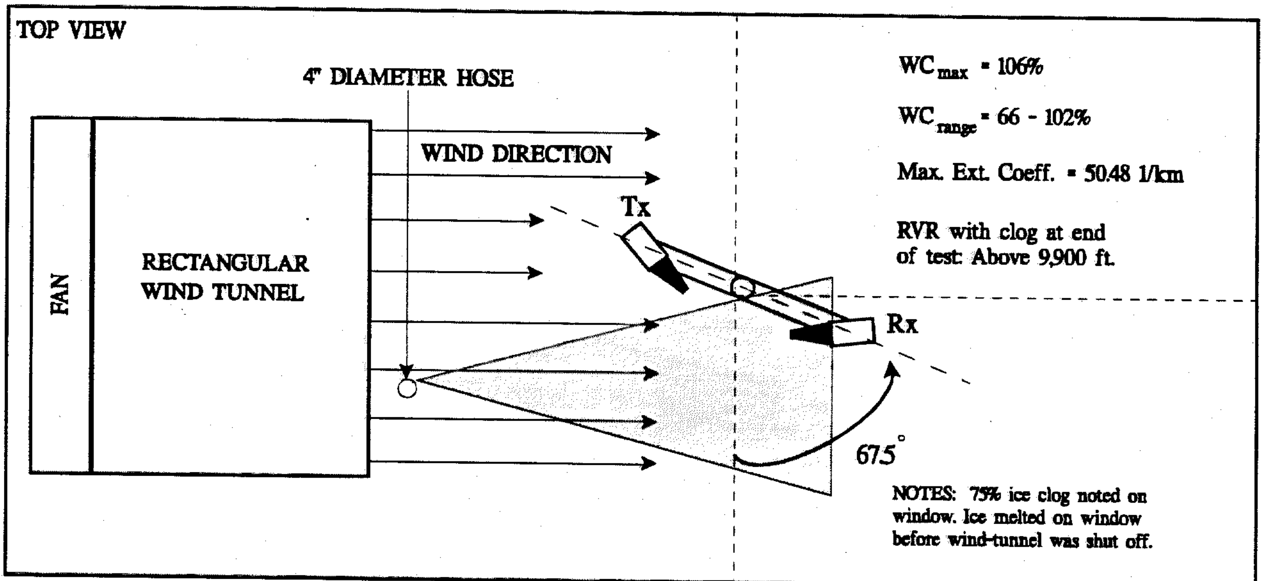


FIGURE 22. LKOUT VS BLOWING SNOW TEST AT 67.5° (RX) - LOCATION: ROWPU CHAMBER

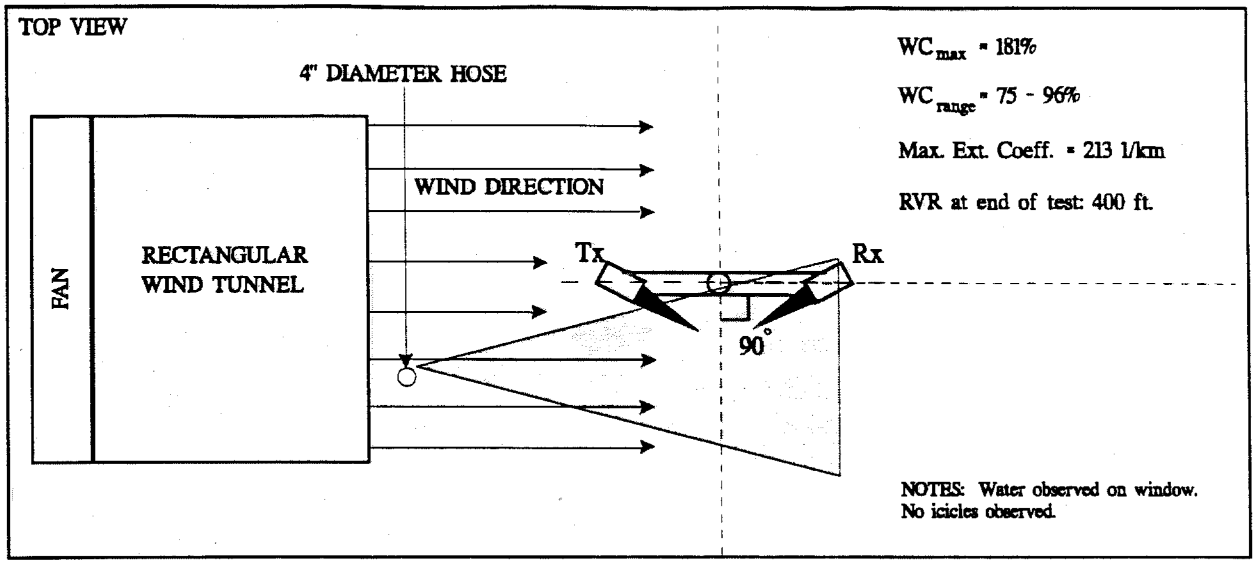


FIGURE 23. LKDWN VS BLOWING SNOW TEST AT 90° (RX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

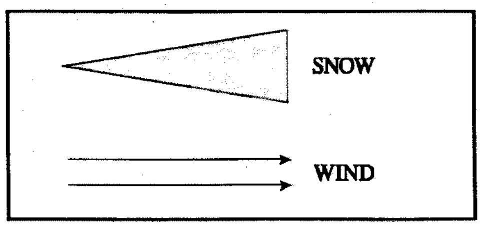
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20° F   Tx = Transmitter

Wind Speed = 20-22 mph   Rx = Receiver

NOTE: All window contaminations are in 5% units



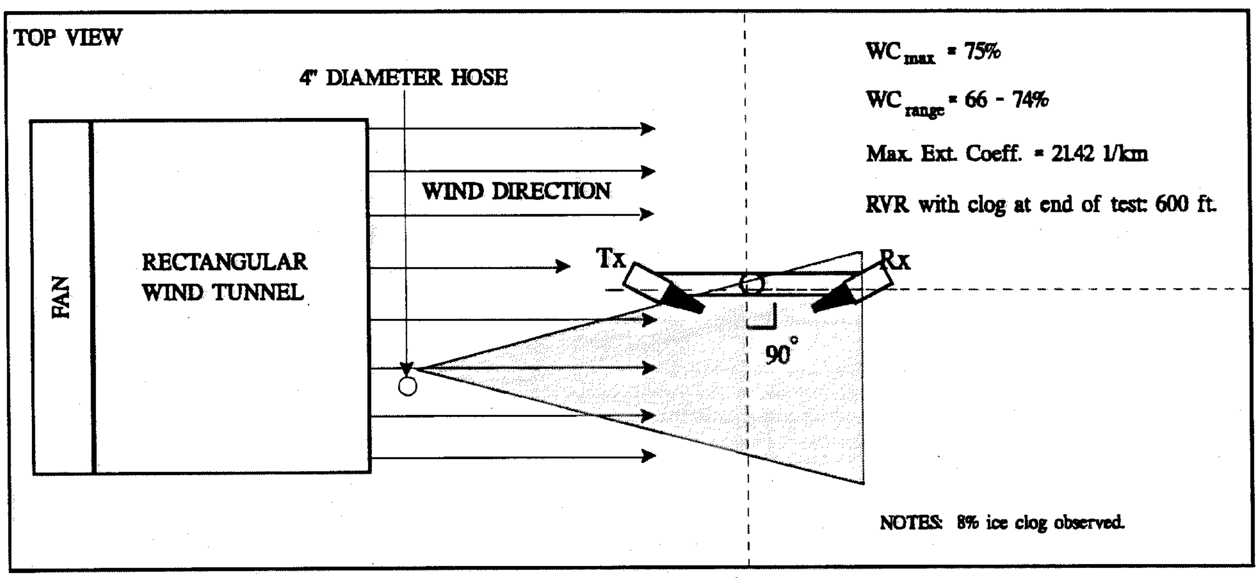


FIGURE 24. LKOUT VS BLOWING SNOW TEST AT 90° (RX) - LOCATION: ROWPU CHAMBER

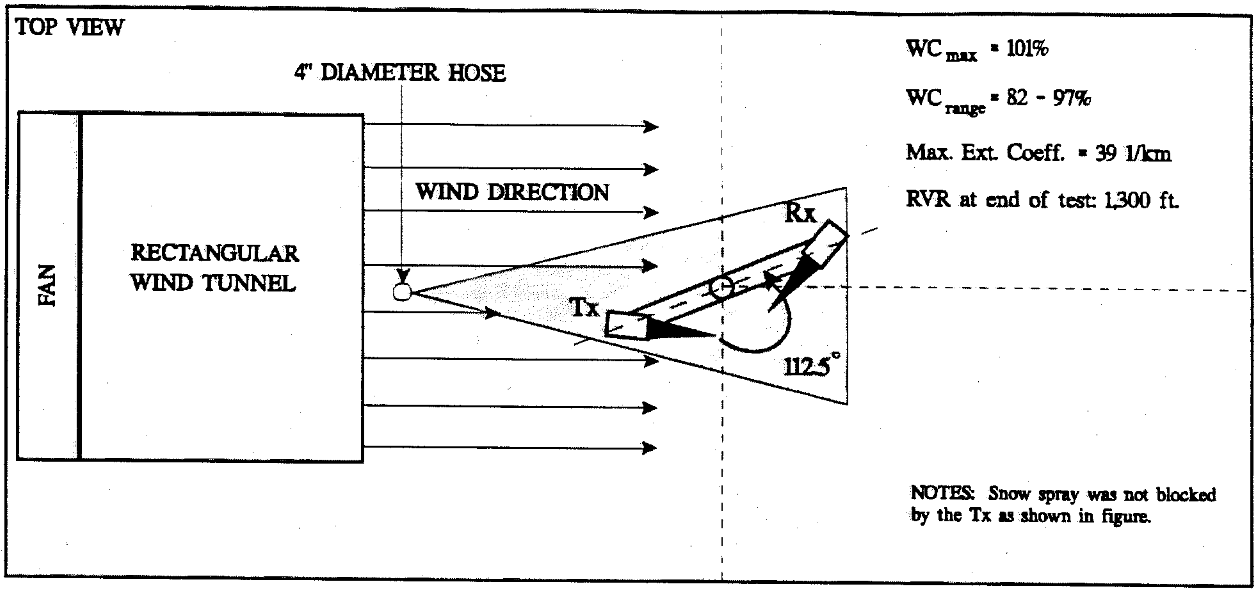


FIGURE 25. LKDWN VS BLOWING SNOW TEST AT 112.5° (RX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

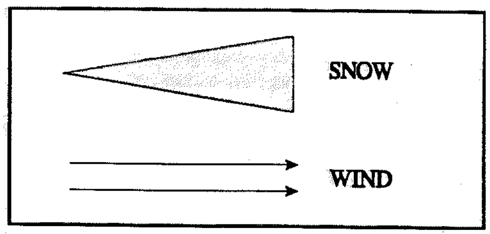
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20° F   Tx = Transmitter

Wind Speed = 20-22 mph   Rx = Receiver

NOTE: All window contaminations are in .5% units



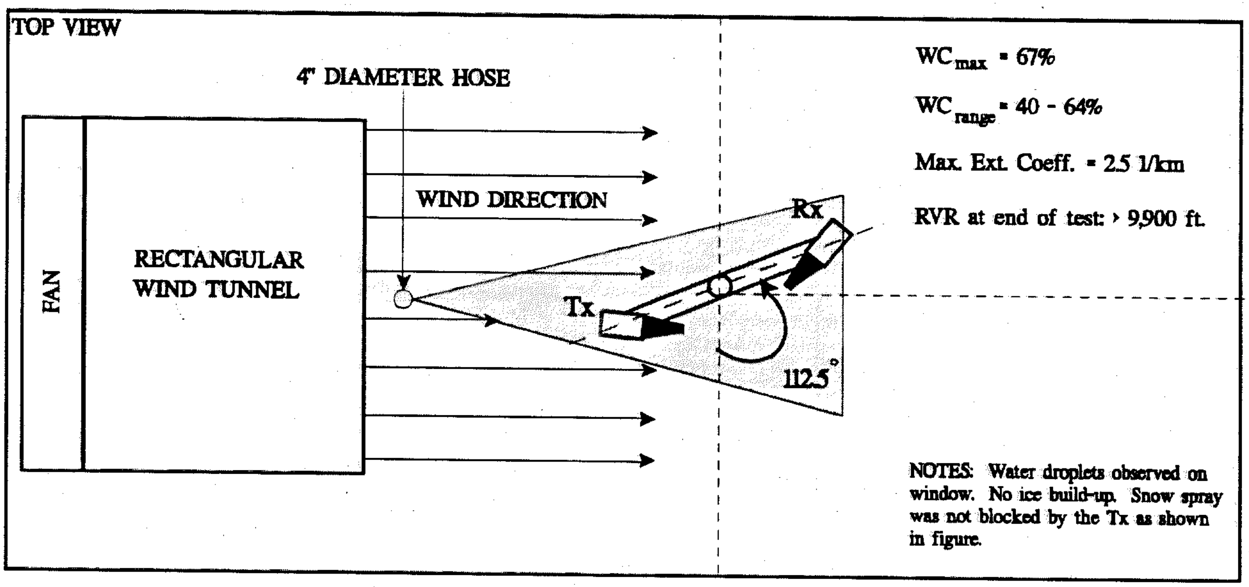


FIGURE 26. LKOUT VS BLOWING SNOW TEST AT 112.5° (RX) - LOCATION: ROWPU CHAMBER

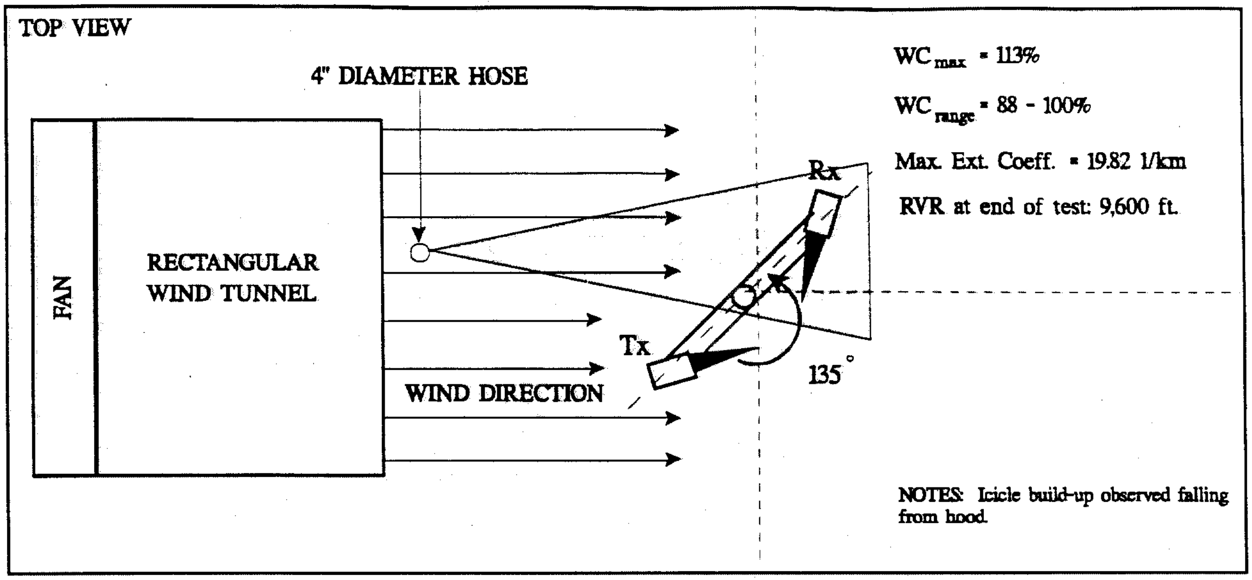


FIGURE 27. LKDWN VS BLOWING SNOW TEST AT 135° (RX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

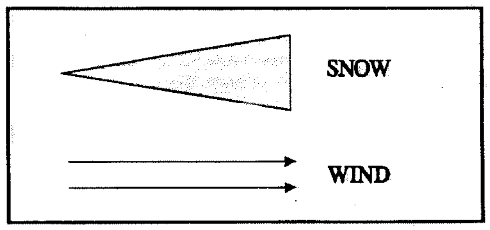
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20° F   Tx = Transmitter

Wind Speed = 20-22 mph   Rx = Receiver

NOTE: All window contaminations are in .5% units



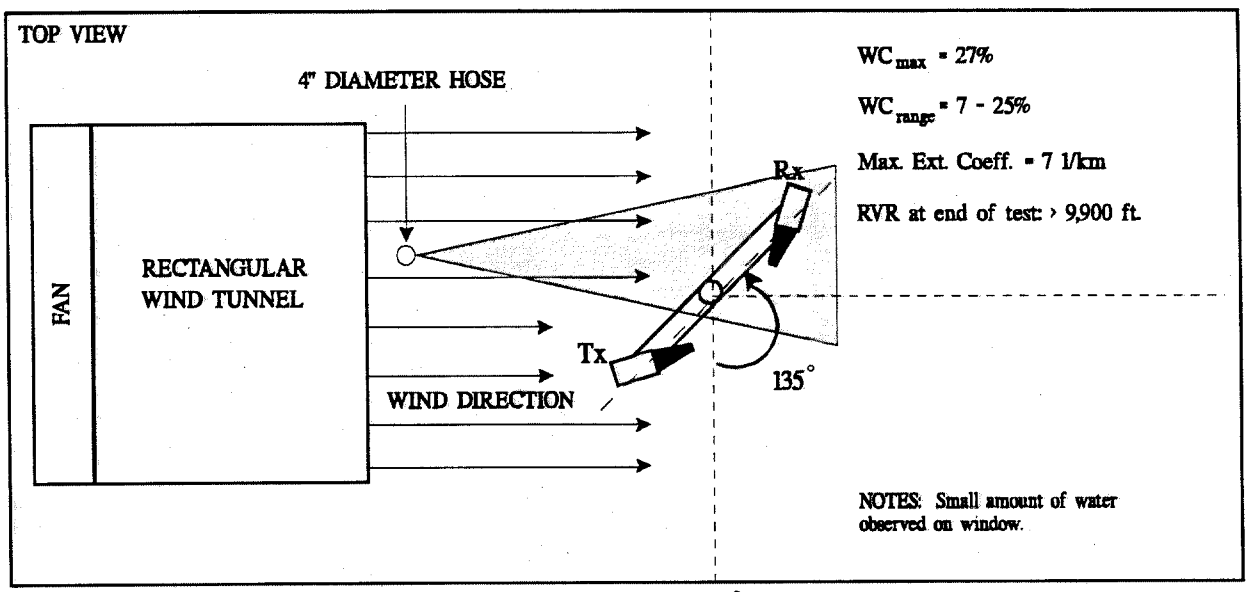


FIGURE 28. LKOUT VS BLOWING SNOW TEST AT 135° (RX) - LOCATION: ROWPU CHAMBER

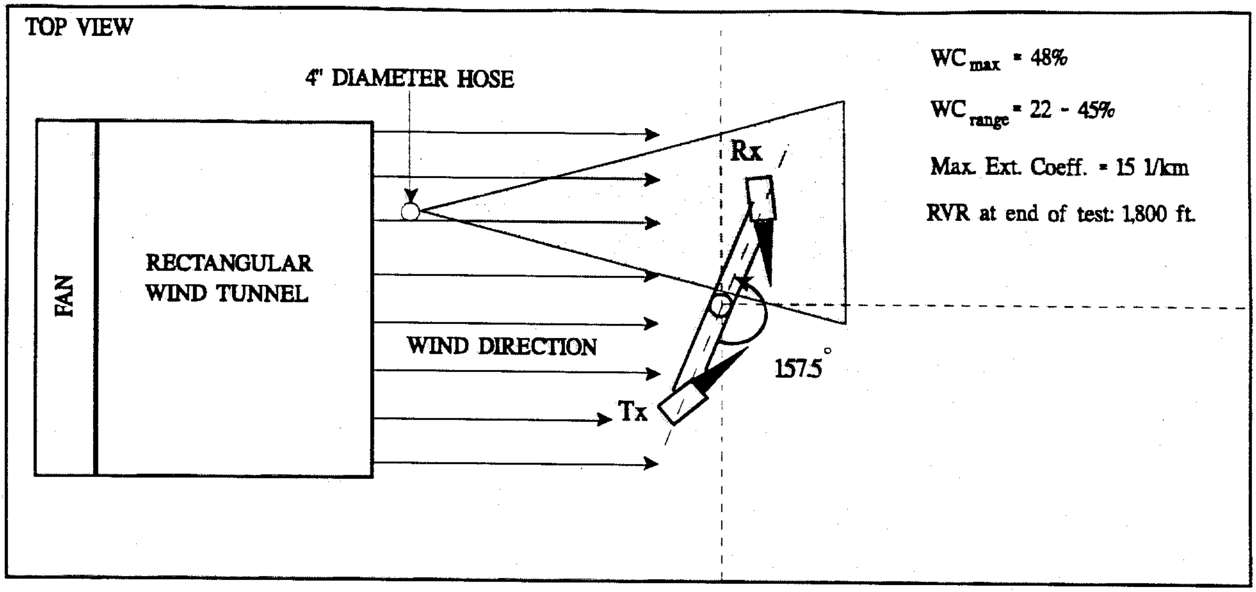
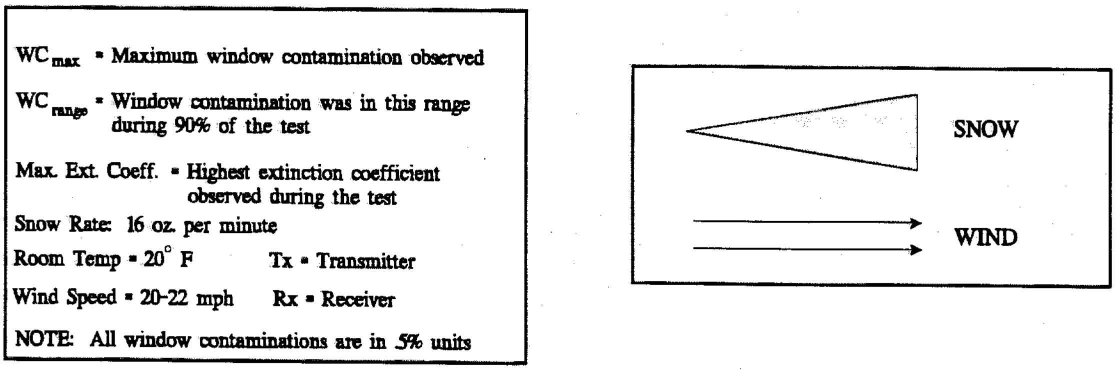


FIGURE 29. LKDWN VS BLOWING SNOW TEST AT 157.5° (RX) - LOCATION: ROWPU CHAMBE



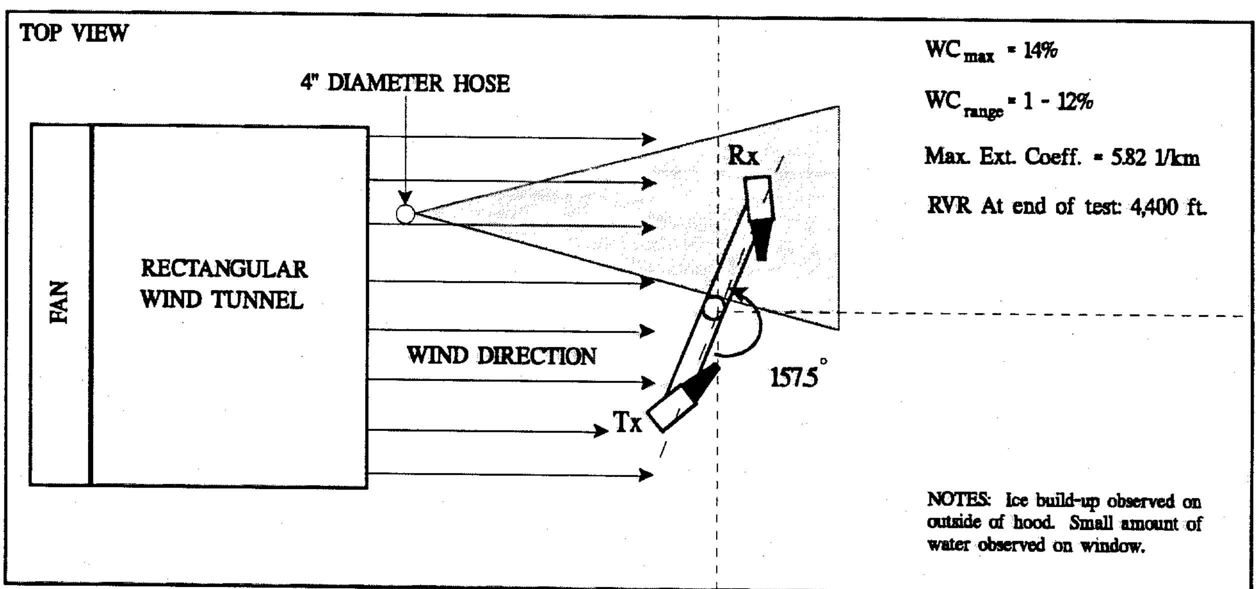


FIGURE 30. LKOUT VS BLOWING SNOW TEST AT 157.5° (RX) - LOCATION: ROWPU CHAMBER

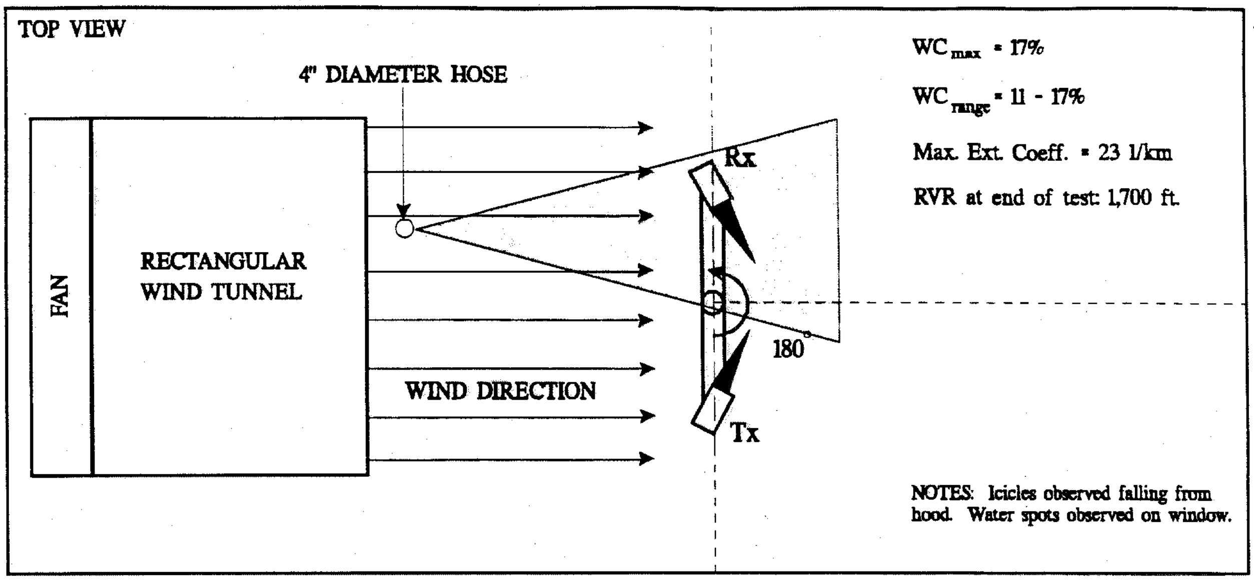


FIGURE 31. LKDWN VS BLOWING SNOW TEST AT 180° (RX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

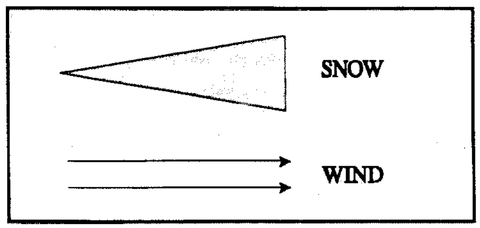
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20° F   Tx = Transmitter

Wind Speed = 20-22 mph   Rx = Receiver

NOTE: All window contaminations are in .5% units



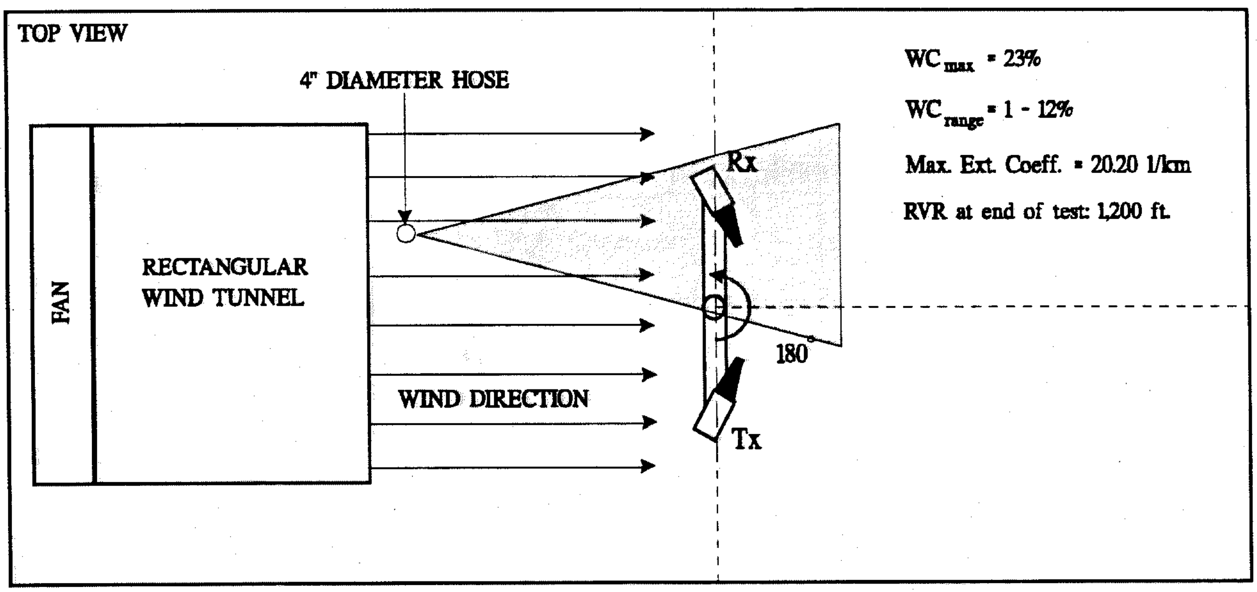


FIGURE 32. LKOUT VS BLOWING SNOW TEST AT 180° (RX) - LOCATION: ROWPU CHAMBER

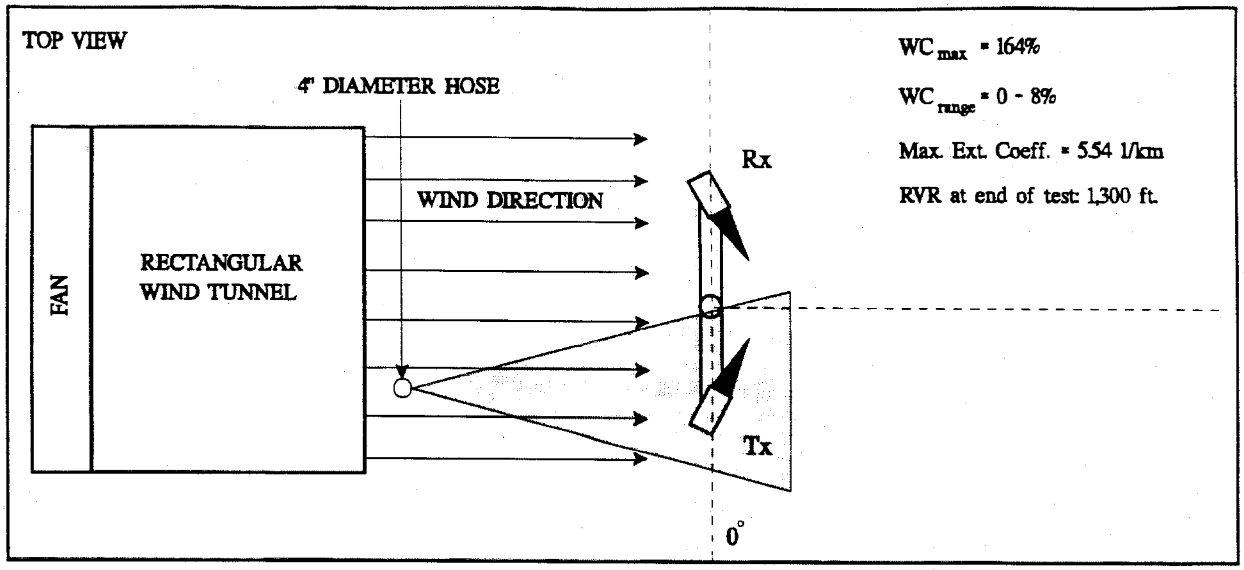


FIGURE 33. LKDWN VS BLOWING SNOW TEST AT 0° (TX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

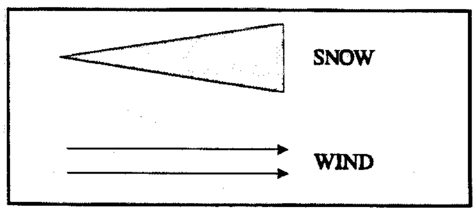
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20° F   Tx = Transmitter

Wind Speed = 20-22 mph   Rx = Receiver

NOTE: All window contaminations are in .5% units



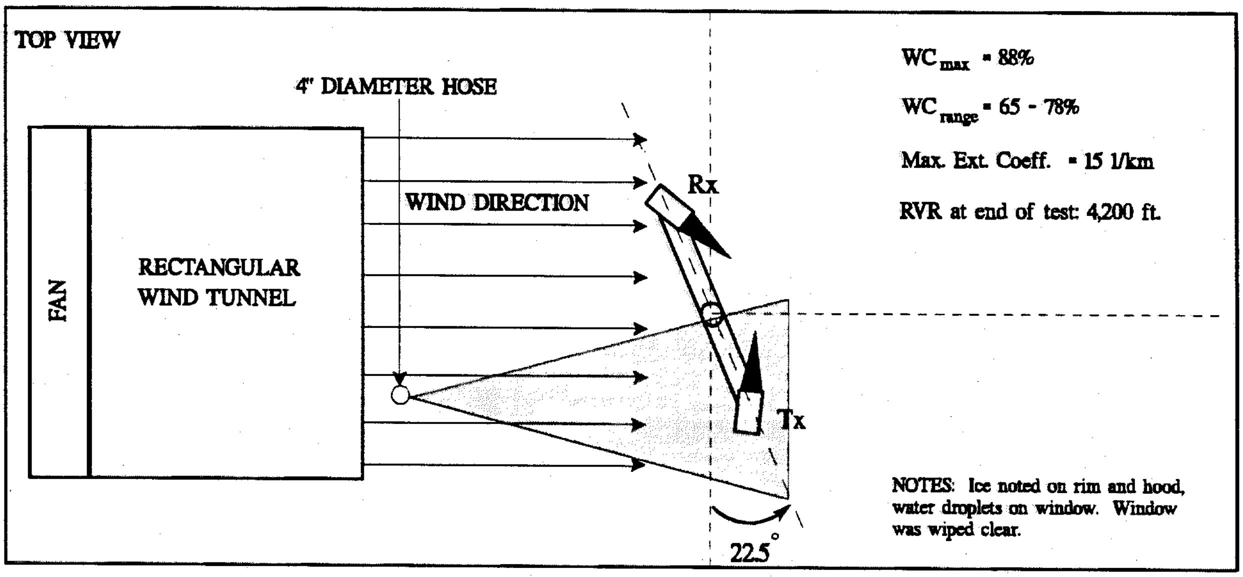


FIGURE 34. LKDWN VS BLOWING SNOW TEST AT 22.5° (TX) - LOCATION: ROWPU CHAMBER

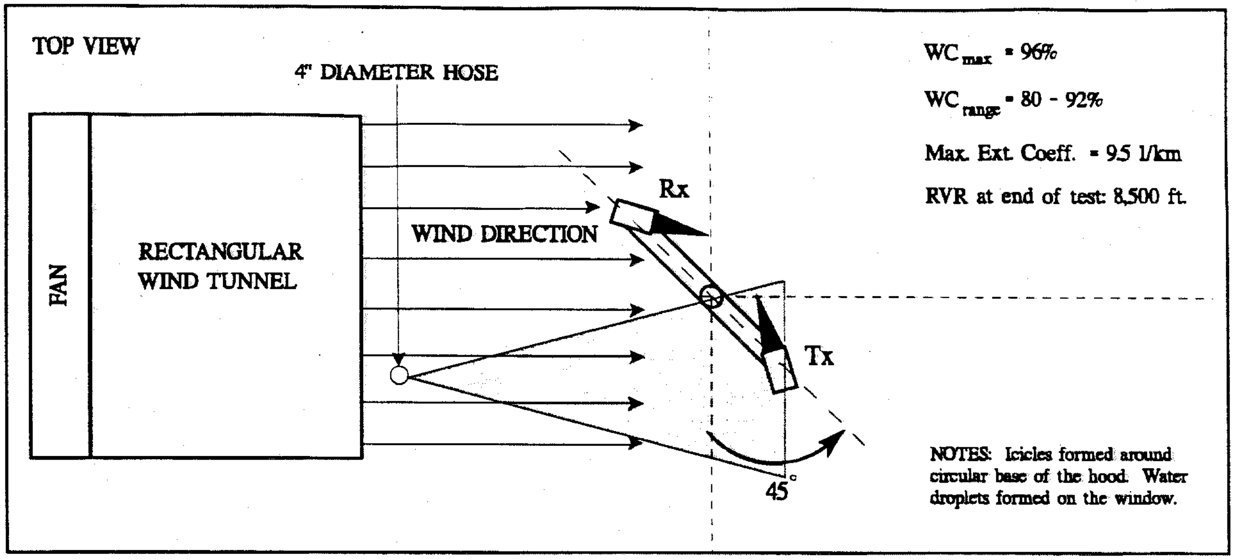


FIGURE 35. LKDWN VS BLOWING SNOW TEST AT 45 °(TX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

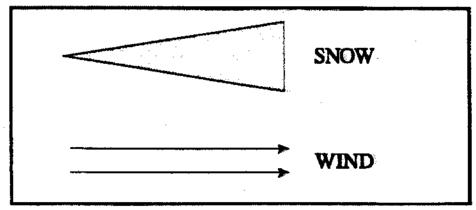
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20° F Tx = Transmitter

Wind Speed = 20-22 mph Rx = Receiver

NOTE: All window contaminations are in .5% units



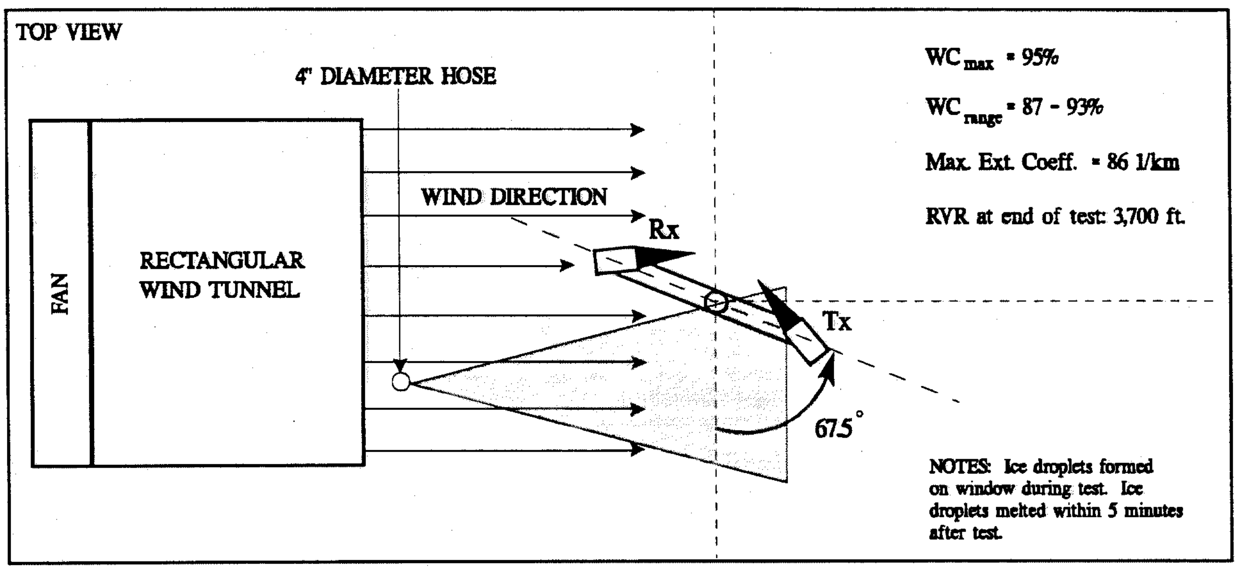


FIGURE 36. LKDWN VS BLOWING SNOW TEST AT 67.5 °(TX) - LOCATION: ROWPU CHAMBER

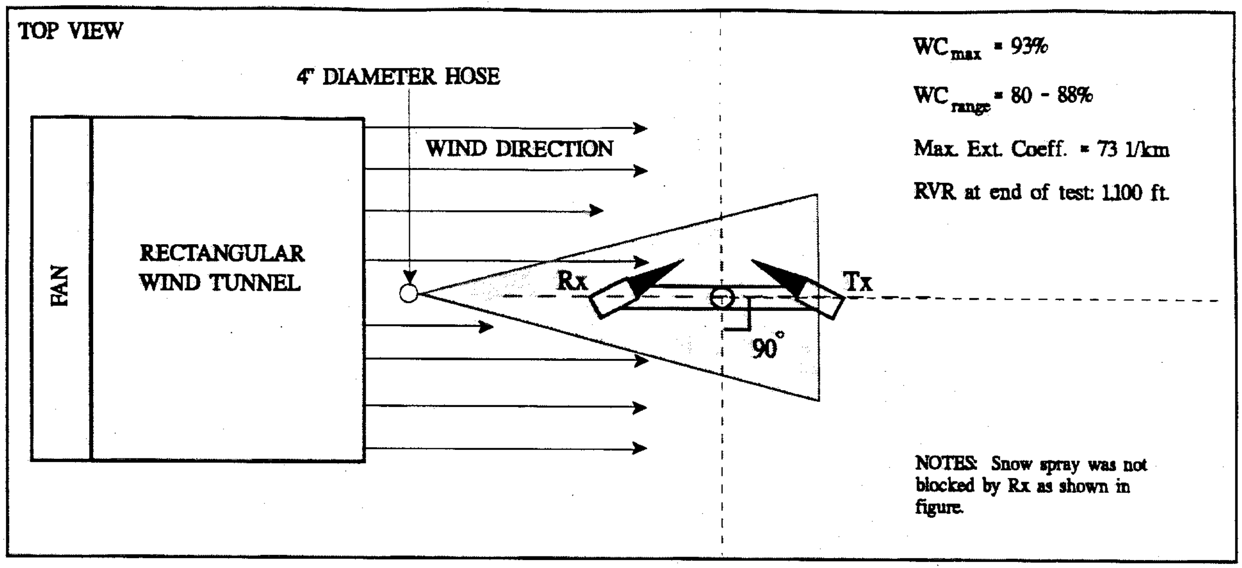


FIGURE 37. LKDWN VS BLOWING SNOW TEST AT 90 °(TX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

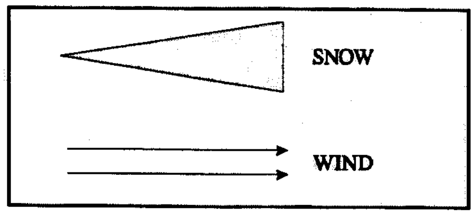
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20° F　　Tx = Transmitter

Wind Speed = 20-22 mph　　Rx = Receiver

NOTE: All window contaminations are in .5% units



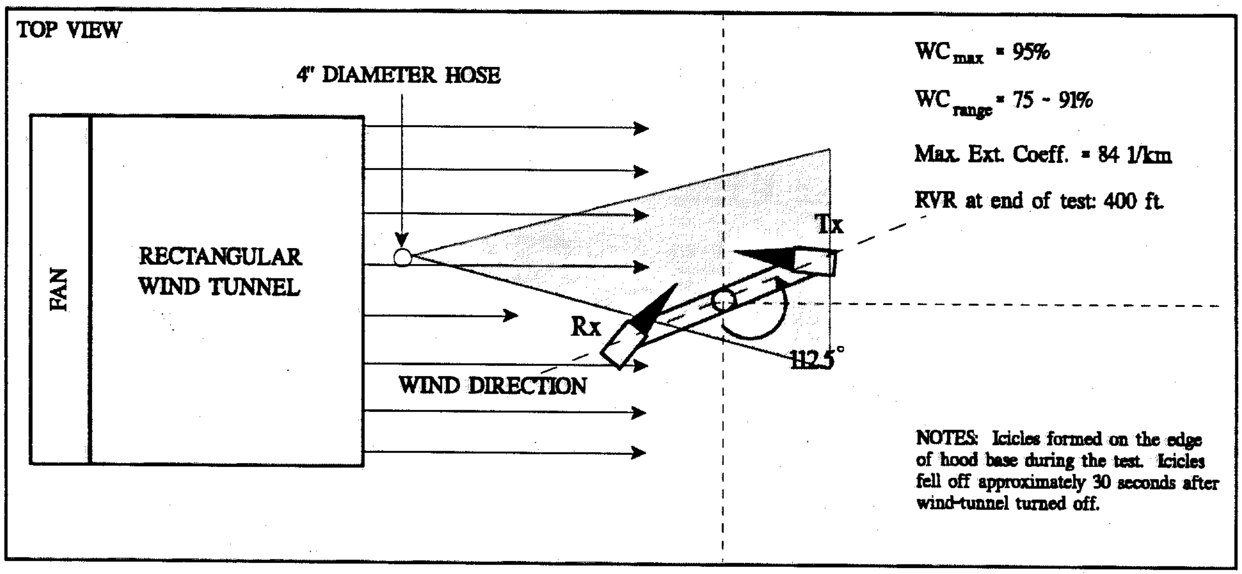


FIGURE 38. LKDWN VS BLOWING SNOW TEST AT 112.5 °(TX) - LOCATION: ROWPU CHAMBER

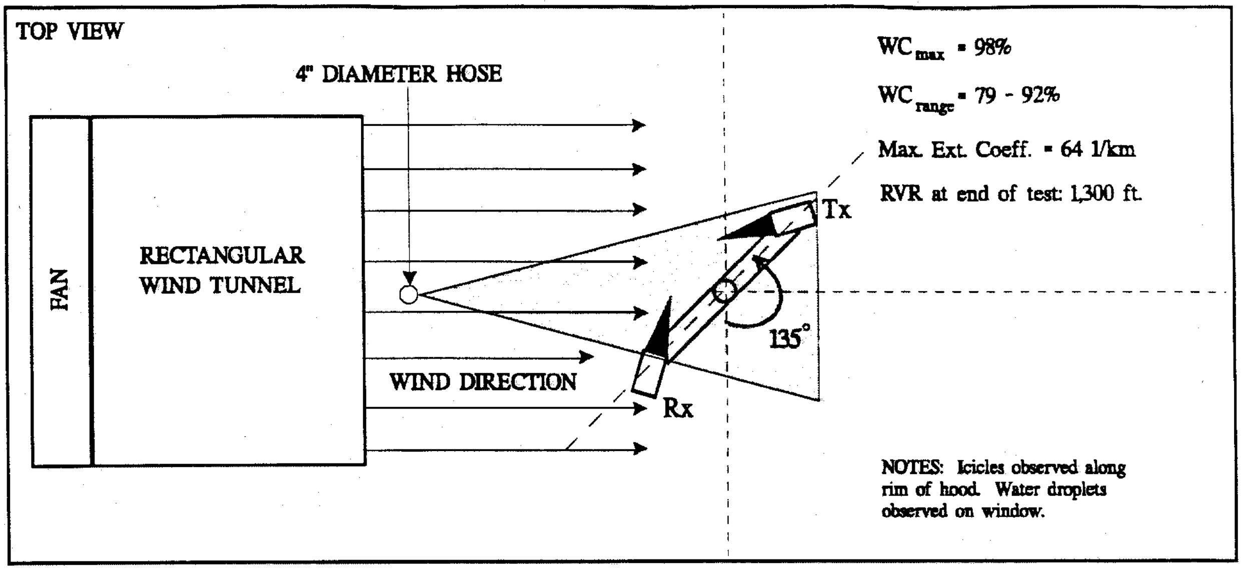


FIGURE 39. LKDWN VS BLOWING SNOW TEST AT 135° (TX) - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

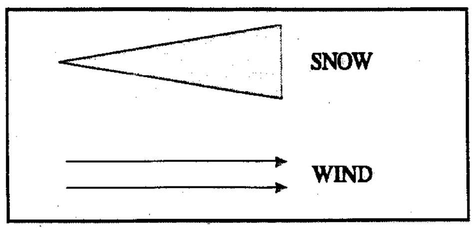
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20° F　　Tx = Transmitter

Wind Speed = 20-22 mph　　Rx = Receiver

NOTE: All window contaminations are in .5% units



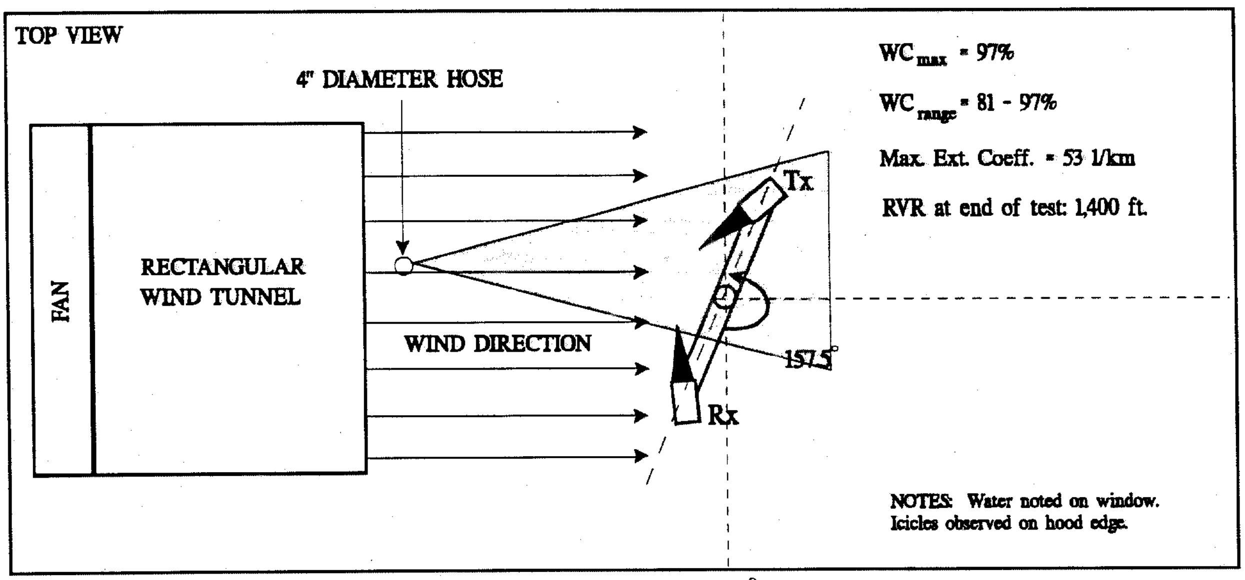
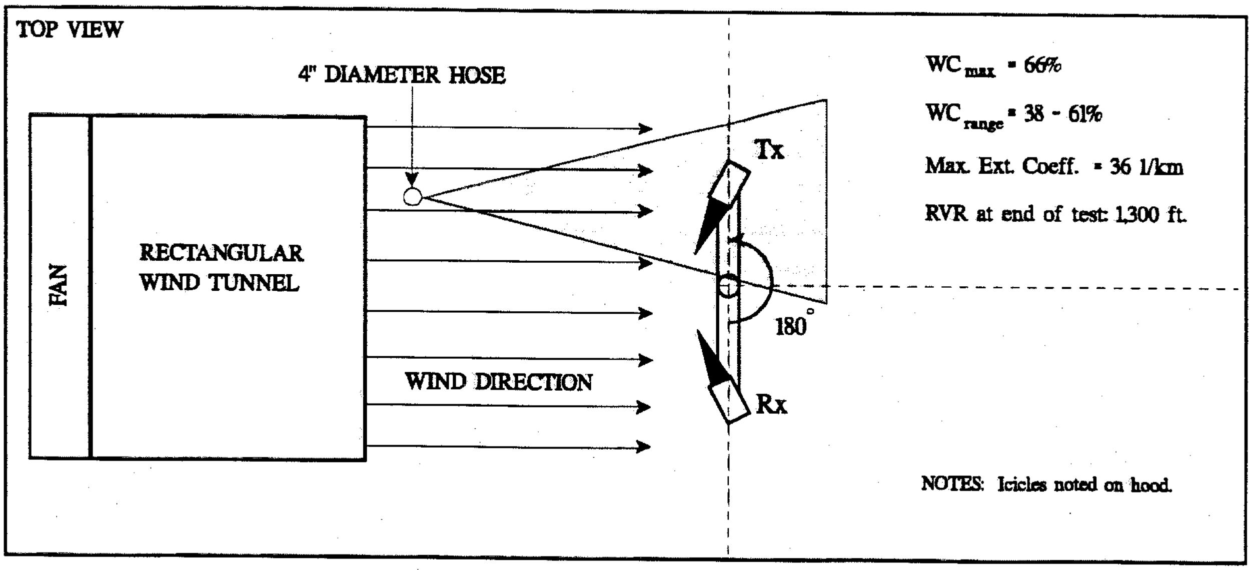


FIGURE 40. LKDWN VS BLOWING SNOW TEST AT 157.5° (TX) - LOCATION: ROWPU CHAMBER



WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 20° F   Tx = Transmitter

Wind Speed = 20-22 mph   Rx = Receiver

NOTE: All window contaminations are in .5% units

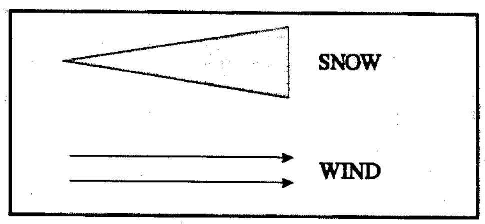


FIGURE 41. LKDWN VS BLOWING SNOW TEST AT 180°(TX) - LOCATION: ROWPU CHAMBER

5.3.9 Angular Blowing Snow with Calibration Plate Test.

The objective of this test was to collect additional data on the relationship between extinction coefficient loss with precipitation on the VS window. Angles in which the VS was least resistant to high window signals and extinction coefficient fluctuations, were chosen for the data collection.

From the angular blowing snow test results, these angles were determined to be ∠112.5° and ∠135°. Using these angles, the blowing snow test was repeated with the calibration plate installed. The known reference provided by the calibration plate allowed the extinction coefficient loss with precipitation on the VS window to be measured.

This test was conducted on the Look-Down VS Tx on August 19, 1993, in the ROWPU Chamber. The test equipment was set up as shown in figures 42 and 43. The chamber temperature was approximately 17° F.

5.3.9.1 Results.

No discrepancies were observed in the conduct of this test. Maximum window signal readings of 93 percent and 92 percent were observed for ∠112.5° and ∠135°, respectively. Unlike the tests performed without the calibration plate, icicles were not observed along the hood base or rim.

5.3.9.2 Conclusion/Comments.

Lack of discrepancies in test conduct and the occurrence of sustained significant window signal readings indicate the test data can be used for determining the relationship between extinction coefficient loss and window precipitation. Although the lack of icicles suggest that some part of the test execution or conditions had changed, the occurrence of similar window signal readings; i.e., 98 percent without calibration plate and 93 percent with calibration plate for ∠112.5°, indicate the VS response to blowing snow at these angles was relatively consistent for both tests.

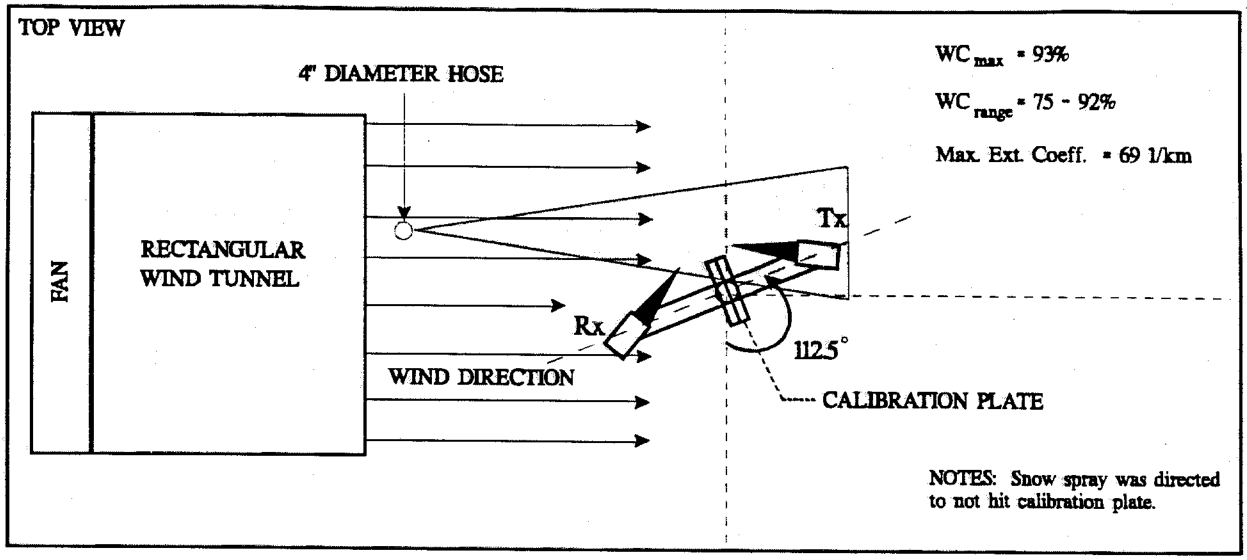


FIGURE 42. LKDWN VS BLOWING SNOW TEST W/ CALIBRATION PLATE (TX) AT 112.5° - LOCATION: ROWPU CHAMBER

WC_{max} = Maximum window contamination observed

WC_{range} = Window contamination was in this range during 90% of the test

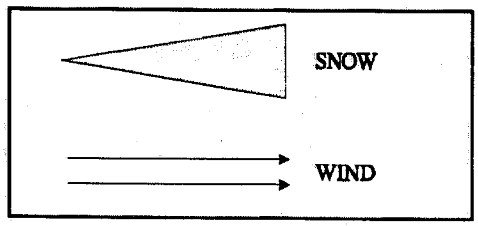
Max. Ext. Coeff. = Highest extinction coefficient observed during the test

Snow Rate: 16 oz. per minute

Room Temp = 17° F Tx = Transmitter

Wind Speed = 20-22 mph Rx = Receiver

NOTE: All window contaminations are in .5% units



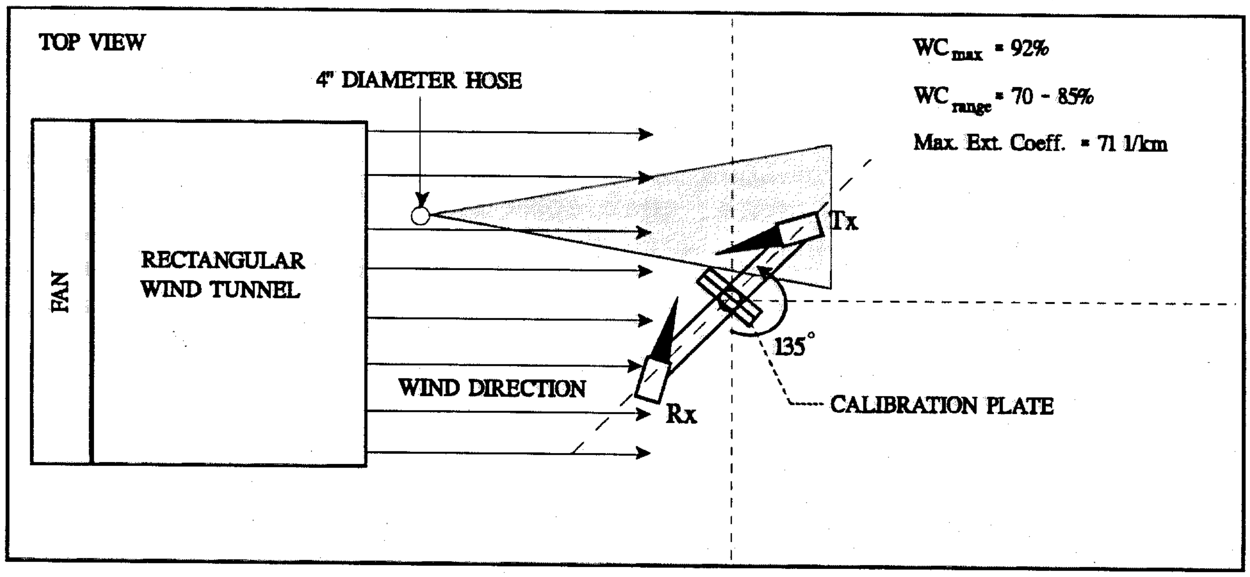


FIGURE 43. LKDWN VS BLOWING SNOW TEST W/ CALIBRATION PLATE (TX) AT 135° - LOCATION: ROWPU CHAMBER

5.3.10 High Intensity Blowing Snow Test.

The objective of this test was to compare the response of the Look-Down and Look-Out configuration VS and the ALS to large amounts, i.e., larger than previous blowing snow tests, of blowing wet snow. The snow gun was used in place of the wind tunnel and sawdust blower used in previous blowing snow tests.

The High Intensity Blowing Snow Test was performed on August 23, 1993, in the ROWPU Chamber. The test equipment, setup, and results are shown in figures 44 through 50. The duration of each scenario ranged from 1 minute and 40 seconds, to 2 minutes and 40 seconds. In the first test scenario, all three sensors i.e., Look-Down VS, Look-Out VS, and ALS, were sprayed simultaneously. In the second scenario, each sensor was sprayed individually. The snow liquid equivalent input rate was 1.2 gallons per minute.

5.3.10.1 Results.

One hundred percent clogs were observed on the Look-Out VS and ALS window. Water was observed on the Look-Out VS window.

5.3.10.2 Conclusion/Comments.

The lack of snow/ice clog formations on the Look-Down VS again indicates that the Look-Down configuration is significantly more resistant to snow/ice-clogging than the Look-Out. The lack of protection of the ALS window could make it susceptible to clogging under severe snow events.

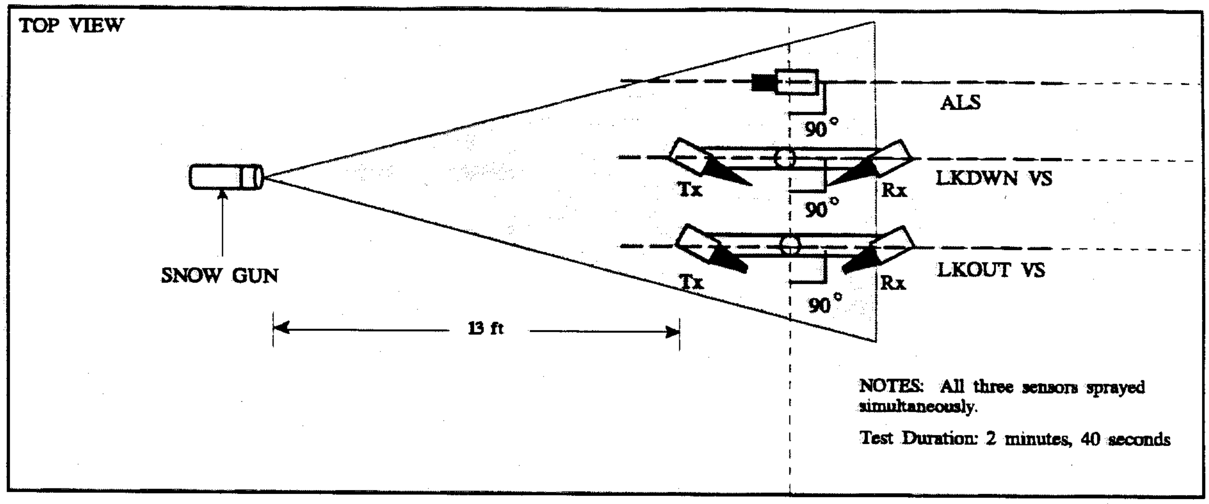


FIGURE 44. BLOWING SNOW TEST W/ SNOW GUN AT 90° LOCATION: ROWPU CHAMBER

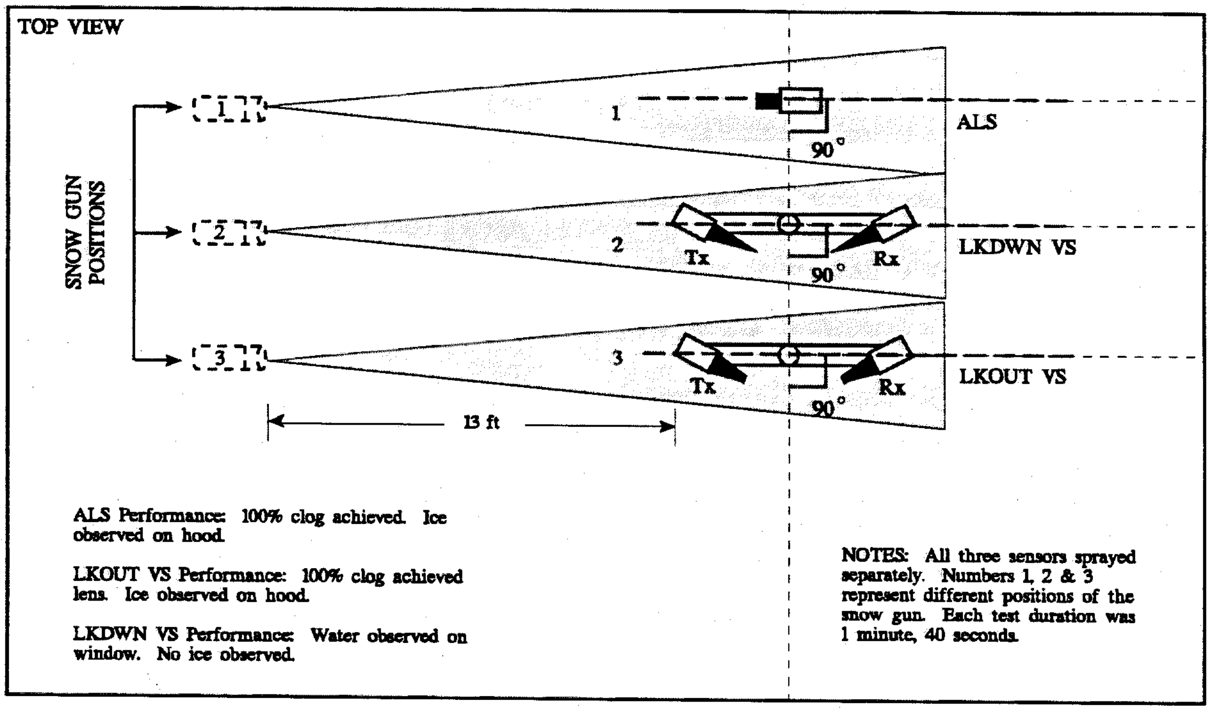


FIGURE 45. BLOWING SNOW TEST W/ SNOW GUN AT 90° LOCATION: ROWPU CHAMBER

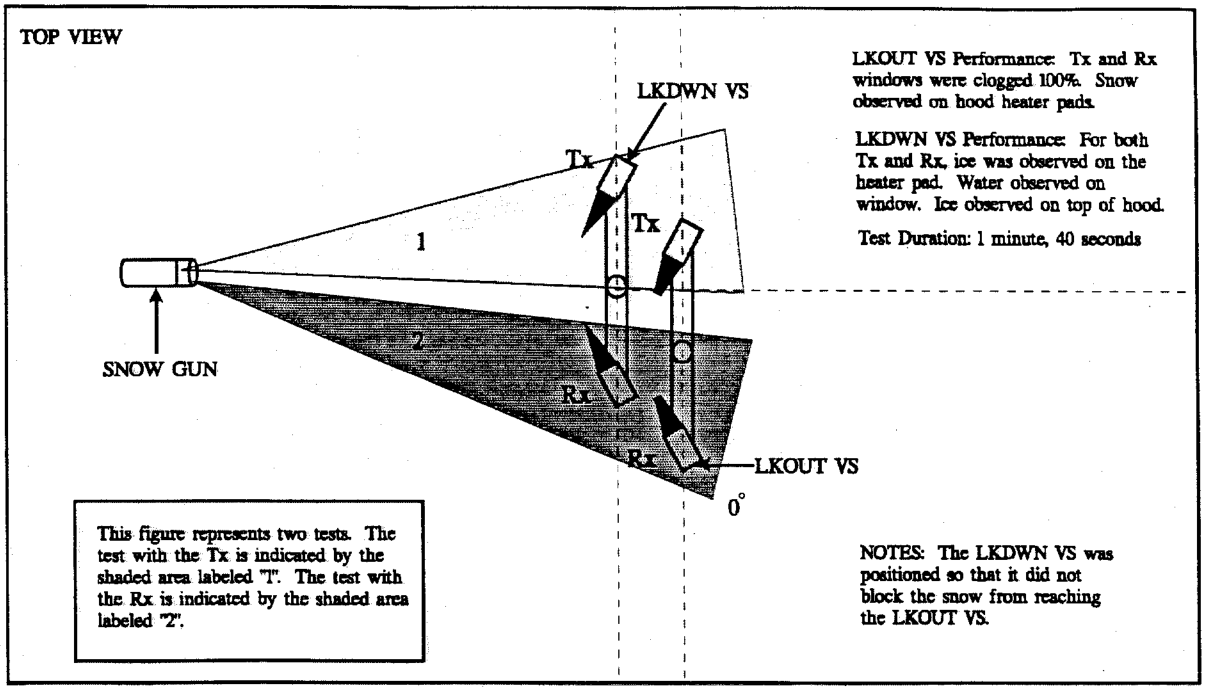


FIGURE 46. BLOWING SNOW TEST W/ SNOW GUN (RX & TX) AT 0° - LOCATION: ROWPU CHAMBER

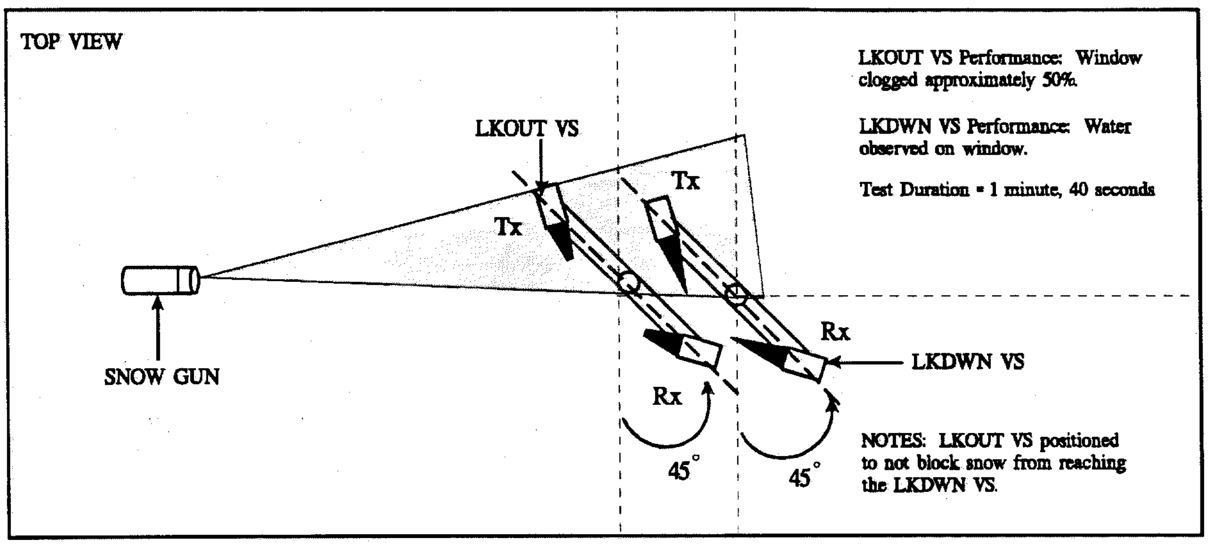


FIGURE 47. BLOWING SNOW TEST W/ SNOW GUN (TX) AT 45° - LOCATION: ROWPU CHAMBER

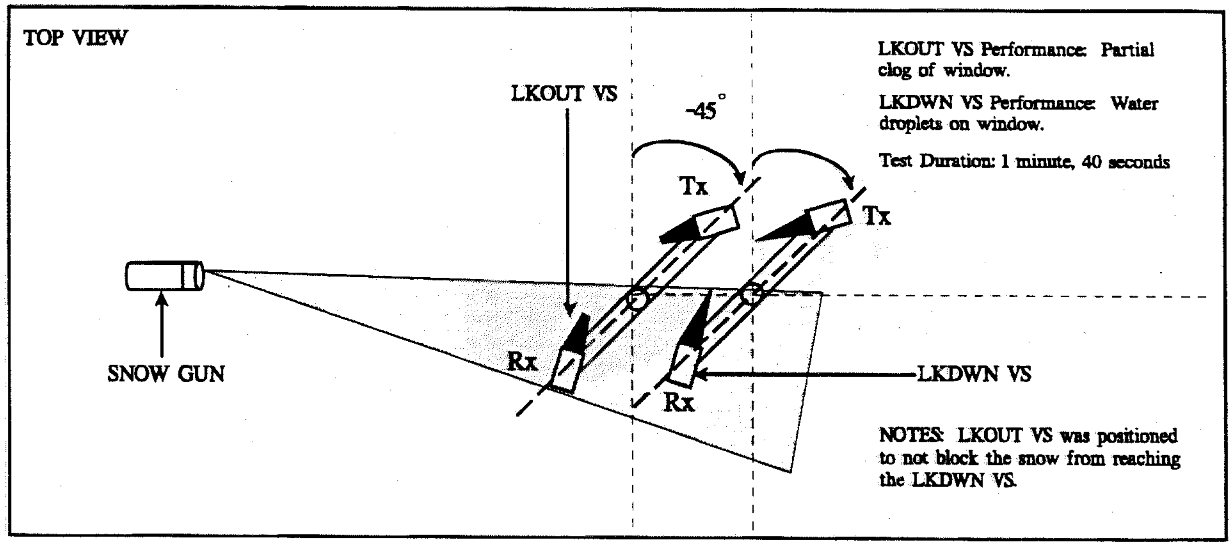


FIGURE 48. BLOWING SNOW TEST W/ SNOW GUN (RX) AT -45°- LOCATION: ROWPU CHAMBER

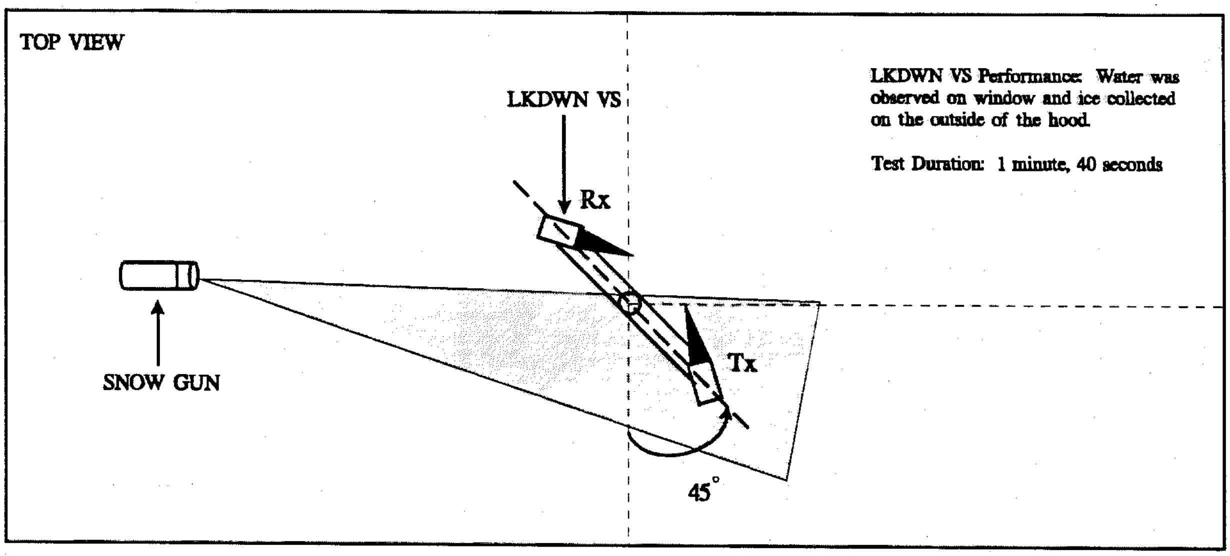


FIGURE 49. BLOWING SNOW TEST W/ SNOW GUN (TX) AT 45°- LOCATION: ROWPU CHAMBER

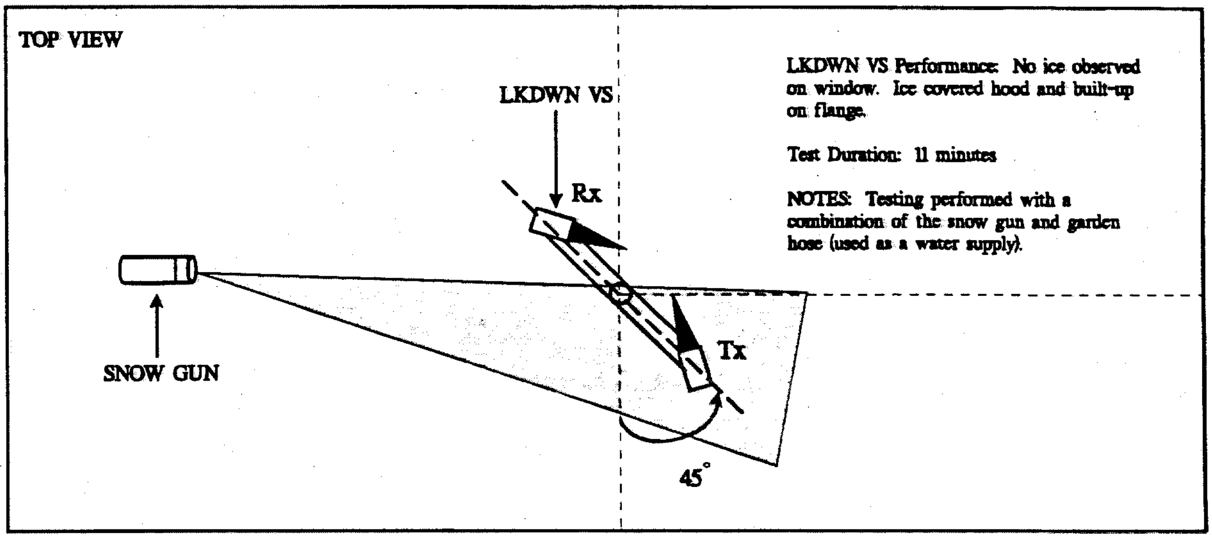


FIGURE 50. BLOWING SNOW TEST W/ SNOW GUN (TX) AT 45°-
LOCATION: ROWPU CHAMBER

5.4 TX AND RX TEMPERATURE DIFFERENCE MEASUREMENTS.

As stated in paragraph 4.5.3, these tests were designed to determine if, under certain wind conditions, significant temperature differences could exist between the Look-Down VS Tx and Rx. Excessive differences would suggest that the design feature of controlling VS Tx and Rx heaters from temperature sensors located in the Tx may need to be modified.

5.4.1 TX RX Temp Diff Test 1.

TX RX Temp Diff Test 1 was conducted on August 20, 1993, in the ROWPU Chamber. The test consisted of two parts. In part one, the Rx was positioned closer to the wind tunnel for most temperature measurements. In part two, the Tx was positioned closer to the fan for similar measurements. Figures 51 through 60 detail the setup and results. The steps conducted for this test were as follows:

a. Placing the Look-Down VS fork at an initial angle of $\angle 0°$ with respect to wind direction;

b. Activating the wind tunnel;

c. Monitoring and recording VS Tx and Rx temperatures until a steady-state temperature was attained;

d. Rotating the Look-Down VS fork $\angle 22.5°$ counterclockwise; and

e. The procedure was repeated until the fork was perpendicular to the starting position.

Other test parameters included a chamber temperature of -5.8° F and a wind tunnel air speed of 20 to 22 mph.

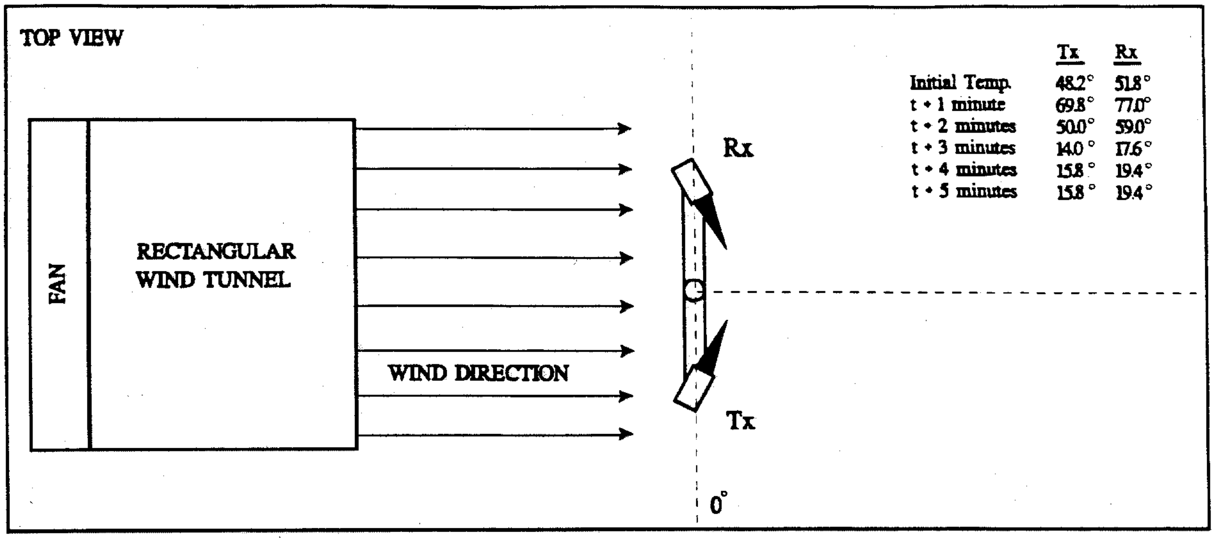


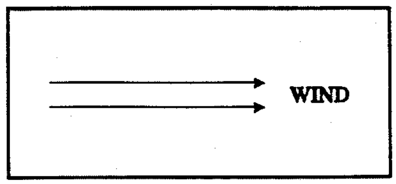
FIGURE 51. TX RX TEMP DIFF TEST 1 AT 0°- LOCATION: ROWPU CHAMBER

Initial Temp. - Temperature of Tx and Rx hood before wind tunnel activated

Room Temp = -5.8° F

Wind Speed = 20-22 mph

NOTE: Last temperature was the steady-state temperature



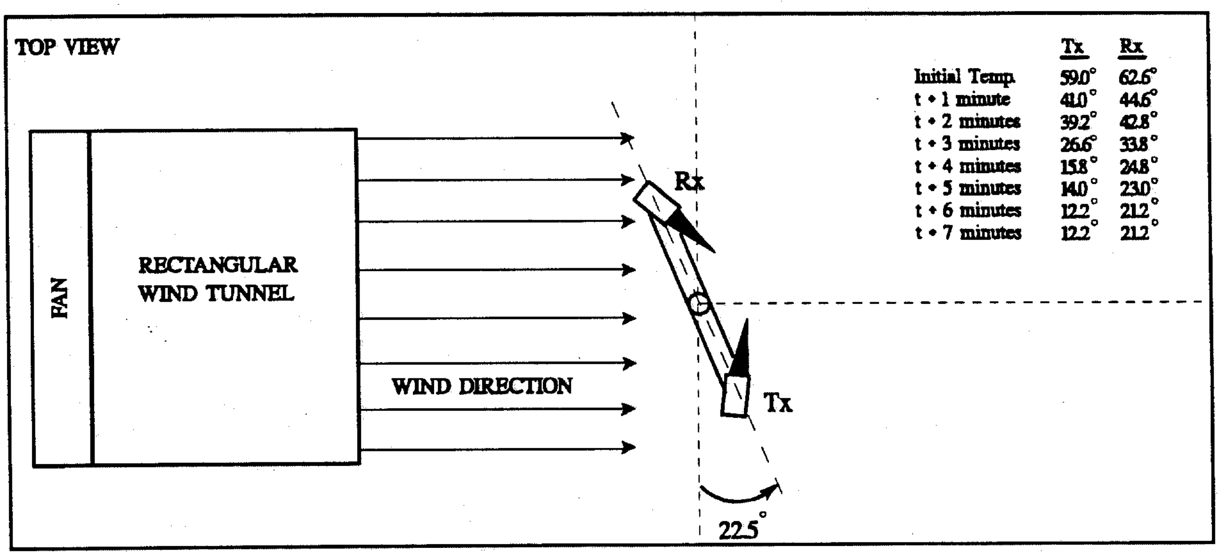
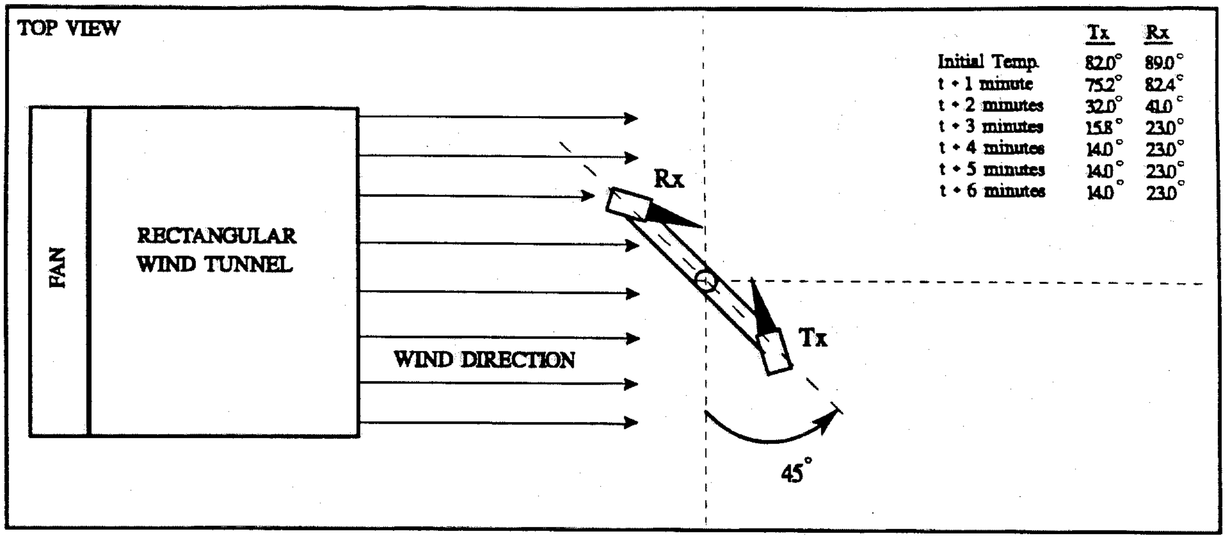


FIGURE 52. TX RX TEMP DIFF TEST 1 AT 22.5°- (RX CLOSER TO FAN) - LOCATION: ROWPU CHAMBER



	Tx	Rx
Initial Temp.	82.0°	89.0°
t = 1 minute	75.2°	82.4°
t = 2 minutes	32.0°	41.0°
t = 3 minutes	15.8°	23.0°
t = 4 minutes	14.0°	23.0°
t = 5 minutes	14.0°	23.0°
t = 6 minutes	14.0°	23.0°

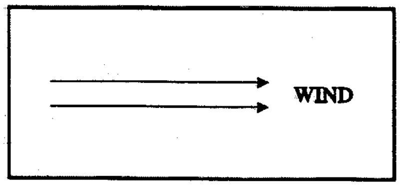
FIGURE 53. TX RX TEMP DIFF TEST 1 AT 45°(RX CLOSER TO FAN) - LOCATION: ROWPU CHAMBER

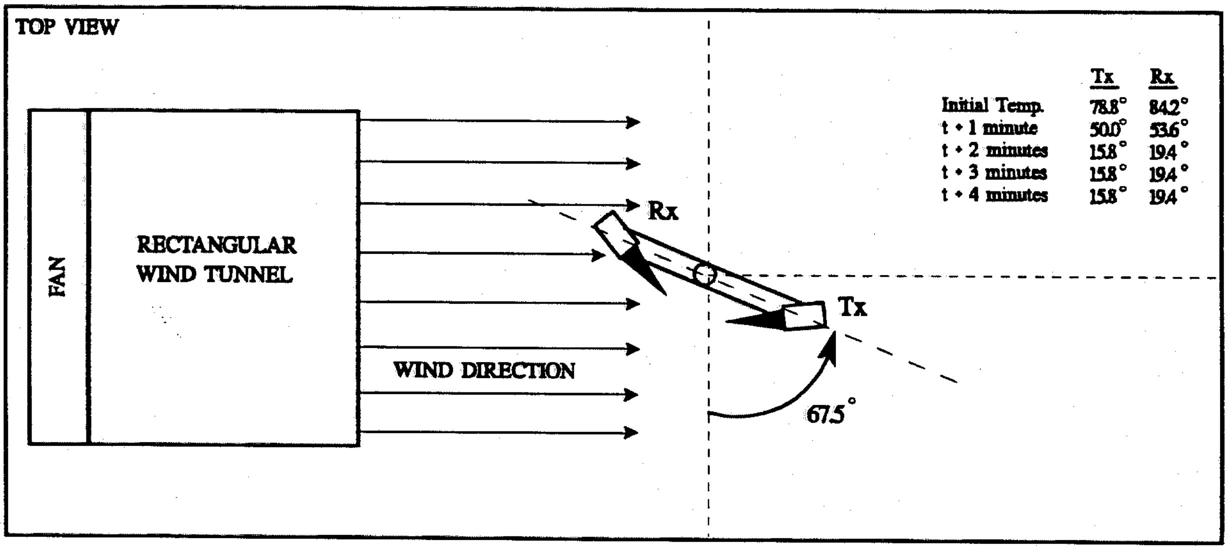
Initial Temp. - Temperature of the Tx and Rx hood before wind tunnel was activated

Room Temp = -5.8 °F

Wind Speed = 20-22 mph

NOTE: Last temperature was the steady-state temperature





	Tx	Rx
Initial Temp.	78.8°	84.2°
t = 1 minute	50.0°	53.6°
t = 2 minutes	15.8°	19.4°
t = 3 minutes	15.8°	19.4°
t = 4 minutes	15.8°	19.4°

FIGURE 54. TX RX TEMP DIFF TEST 1 AT 67.5°(RX CLOSER TO FAN) - LOCATION: ROWPU CHAMBER

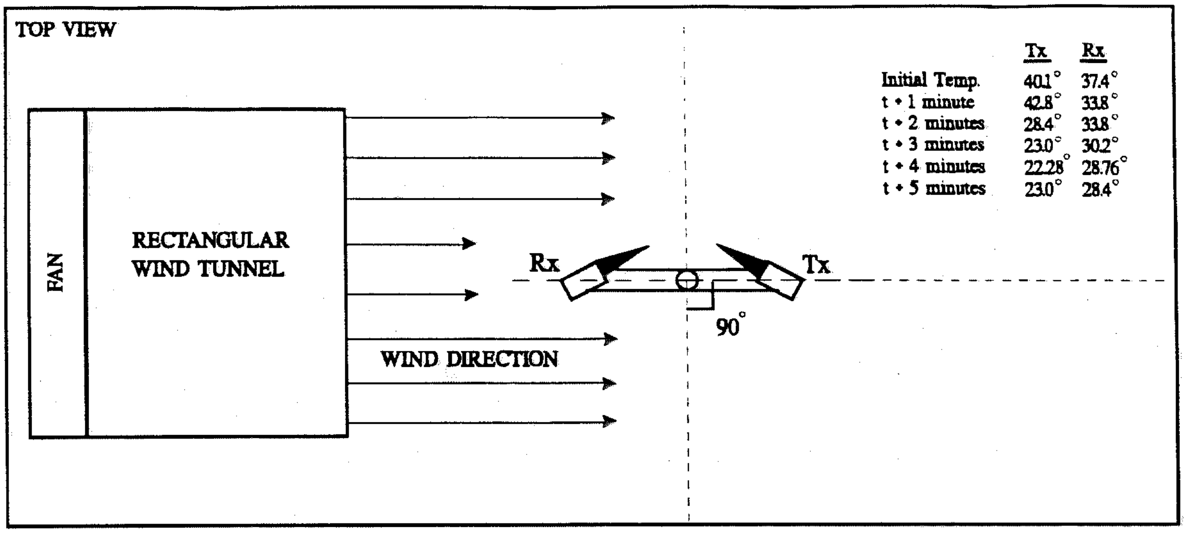


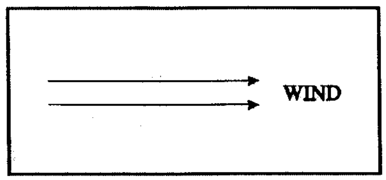
FIGURE 55. TX RX TEMP DIFF TEST 1 AT 90°(RX CLOSER TO FAN) - LOCATION: ROWPU CHAMBER

Initial Temp. - Temperature of the Tx and Rx hood before wind tunnel was activated

Room Temp = -5.8° F

Wind Speed = 20-22 mph

NOTE: Last temperature was the steady-state temperature



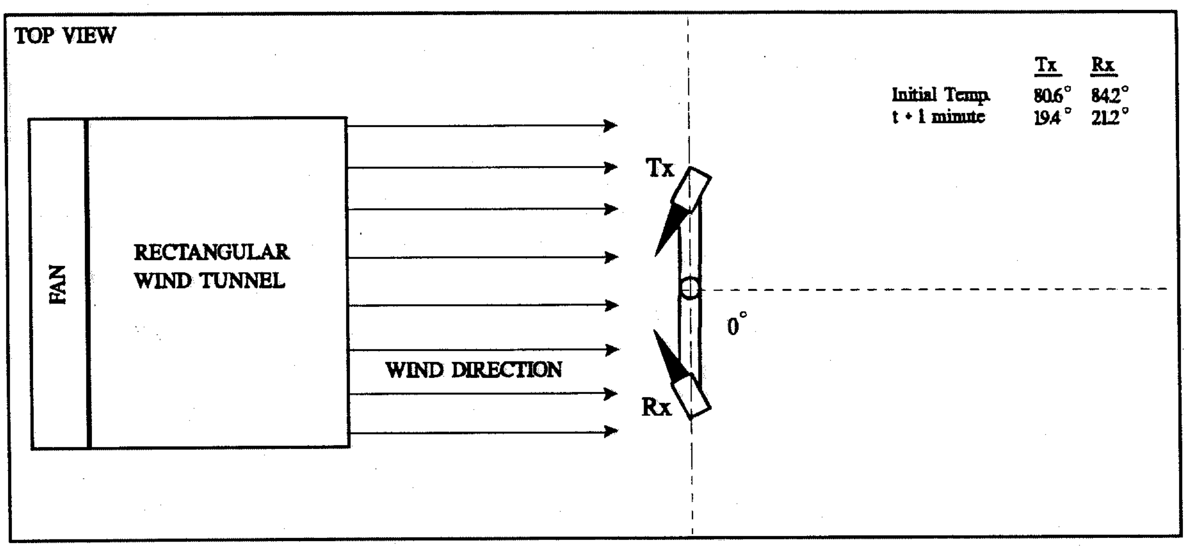


FIGURE 56. TX RX TEMP DIFF TEST 1 AT 0°- LOCATION: ROWPU CHAMBER

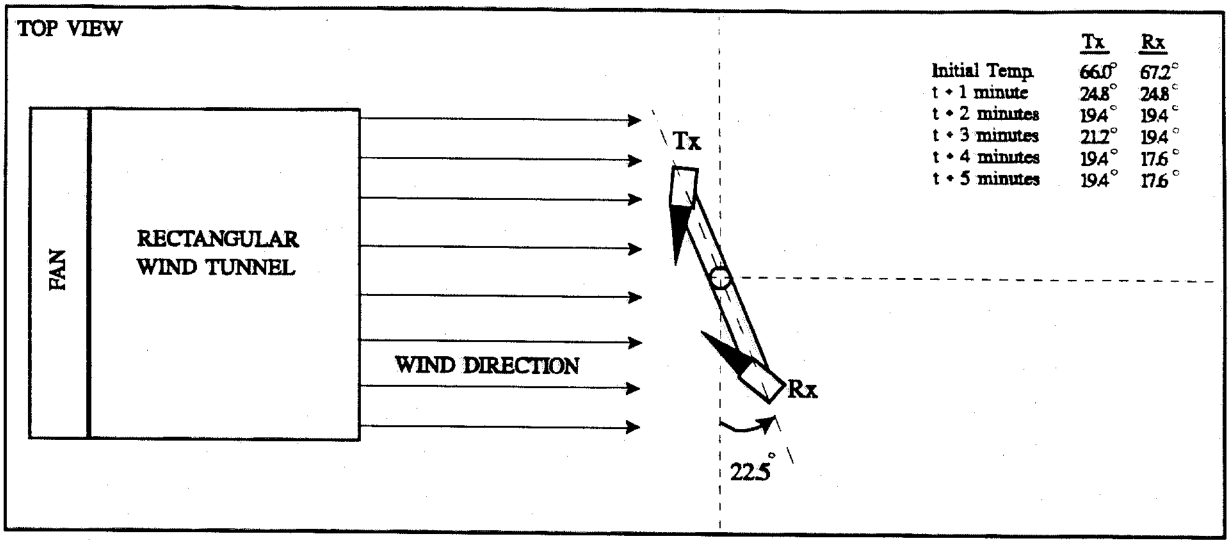


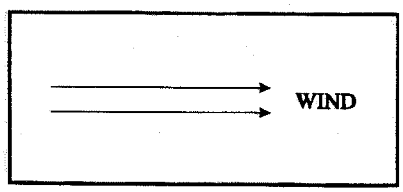
FIGURE 57. TX RX TEM DIFF TEST 1 AT 22.5°(TX CLOSER TO FAN) - LOCATION: ROWPU CHAMBER

Initial Temp. - Temperature of the Tx and Rx hood before wind tunnel was activated

Room Temp • -5.8° F

Wind Speed • 20-22 mph

NOTE: Last temperature was the steady-state temperature



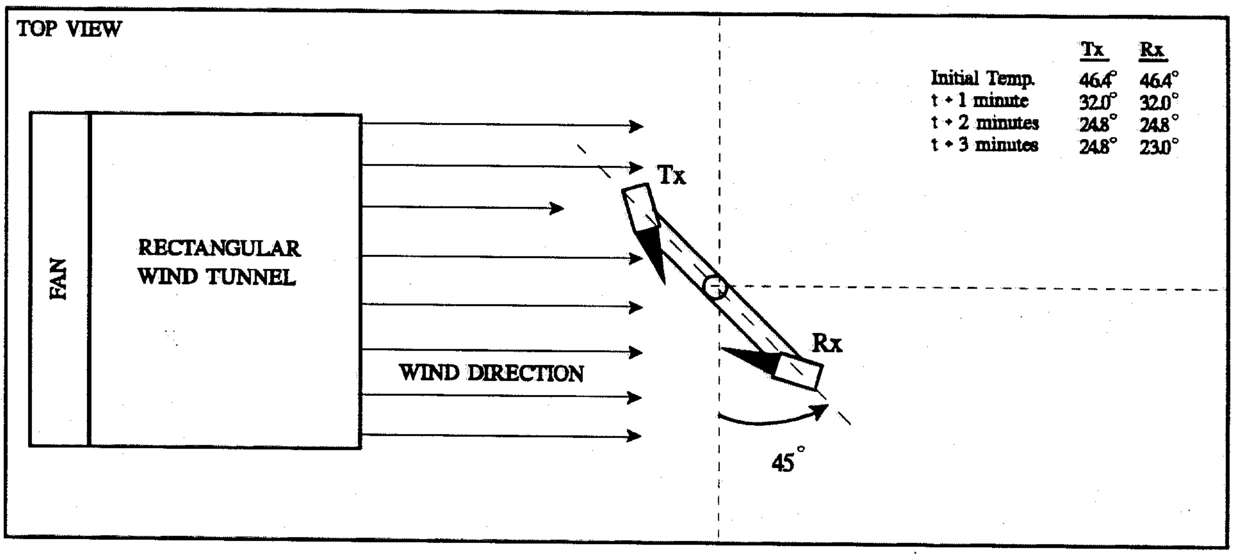


FIGURE 58. TX RX TEMP DIFF TEST 1 AT 45°(TX CLOSER TO FAN) - LOCATION: ROWPU CHAMBER

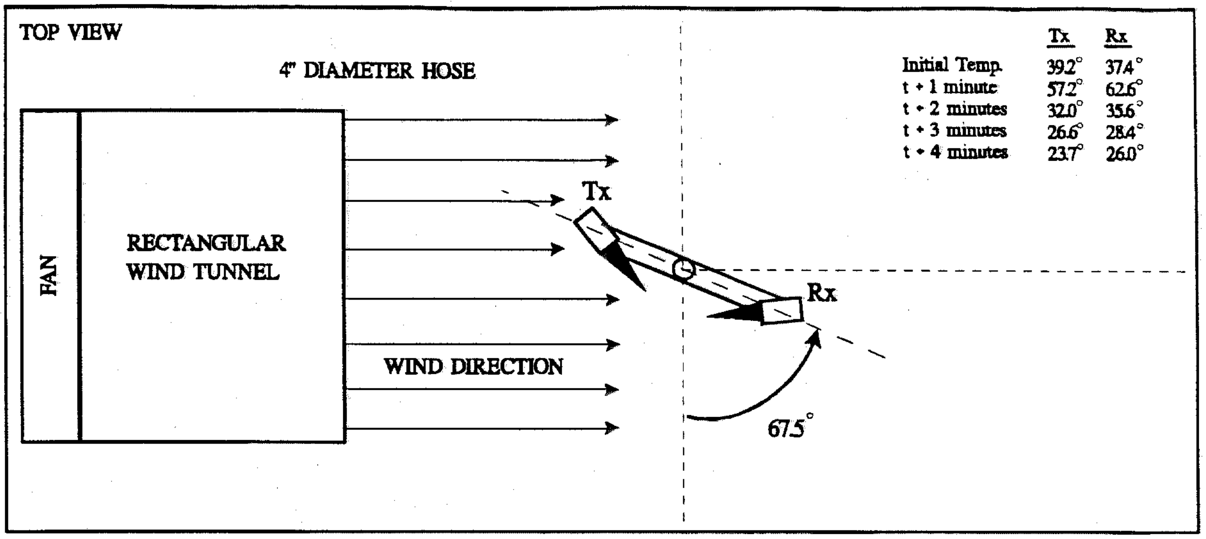


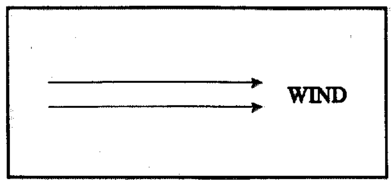
FIGURE 59. TX RX TEMP DIFF TEST AT 67.5°(TX CLOSER TO FAN) - LOCATION: ROWPU CHAMBER

Initial Temp. - Temperature of the Tx and Rx hood before wind tunnel was activated

Room Temp = -5.8° F

Wind Speed = 20-22 mph

NOTE: Last temperature was the steady-state temperature



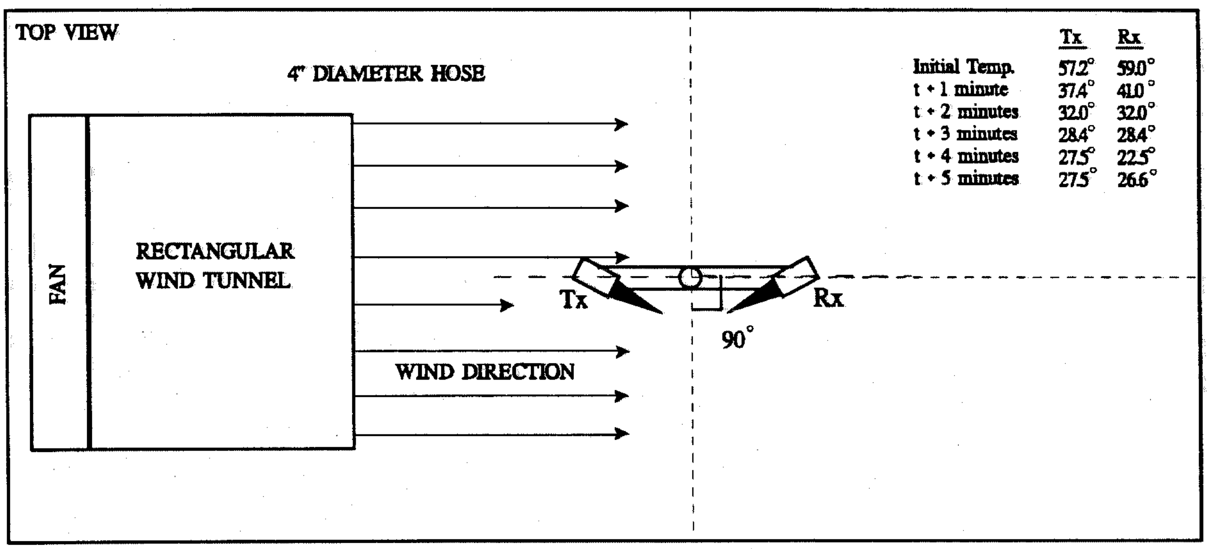


FIGURE 60. TX RX TEMP DIFF TEST 1 AT 90°(TX CLOSER TO FAN) - LOCATION: ROWPU CHAMBER

5.4.1.1 Results.

For each test, the VS reached steady-state temperature within approximately 7 minutes. The VS component i.e., Tx or Rx, which was positioned closest to the wind tunnel usually remained warmer throughout the test. This resulted in scenarios where the Rx temperature was greater than the Tx after steady-state conditions were achieved. This also resulted in scenarios where the Tx temperature was greater than the Rx based on the final position of the Tx and Rx.

Out of 10 sensor fork axis positions, 3 resulted in Rx temperatures which were colder than the Tx. The Rx temperature remained warmer than or equal to the Tx for the remaining positions.

The largest steady-state and transient temperature difference noted between the Tx and Rx was 9°. This occurred with the Rx positioned closer to the fan and as a result, warmer than the Tx. Larger steady-state temperature differences e.g., 5°, were observed when wind was directed at ∠22.5° and ∠45° (figures 52 and 53) than at the remaining angles.

5.4.1.2 Conclusion/Comments.

The results suggest the largest Tx and Rx temperature differences occur with horizontal wind directions that are angular, e.g., ∠22.5°, ∠45°, as opposed to perpendicular, to the sensor fork axis. During the larger temperature differences, e.g., approximately 9° F with 20 mph winds, the Rx is warmer than the Tx and hence, is protected against icing and snow clogging without its heater activated.

Test results where the Rx temperature remained warmer than the Tx for most fork axis positions suggest that the design feature of controlling the Rx heater with the Tx temperature is suitable for proper operation of the VS during icing and clogging conditions. Instances where larger temperature differences were observed between the Tx and Rx also support this conclusion since the Rx remained warmer during test conditions.

5.4.2 TX RX Temp Diff Test 2.

TX RX Temp Diff Test 2 was conducted on August 23, 1993, in the ROWPU Chamber. The objective of this test was to simultaneously compare hood temperatures of the Look-Down and Look-Out configuration VS. The conduct for this test entailed the following:

a. Positioning the Look-Out VS parallel and adjacent to the Look-Out VS (figure 61);

b. Activating the wind tunnel; and

c. Monitoring the VS Tx and Rx temperatures until a steady-state temperature was attained.

Figure 62 indicates the results in graphical form.

5.4.2.1 Results.

The sensors reached steady-state temperatures after approximately 5 minutes of the test. The largest temperature difference observed between each sensor was 2°. For matching angles, temperature differences between each sensor Tx and Rx were approximately the same as observed in TX RX Temp Diff Test 1.

5.4.2.2 Conclusion/Comments.

Small temperature differences, i.e., within 2°, between the Look-Down and Look-Out prototype suggest that the change in design configuration has little or no impact on the sensor hood temperature profile.

As the results of TX RX Temp Diff Test 1 suggest, wind directed perpendicularly to the sensor fork axis appears to cause the least temperature difference between Tx and Rx.

The results indicate that the Tx and Rx temperature differences are small. Hence, a change in heater control scheme based solely on Tx and Rx temperature differences is not warranted.

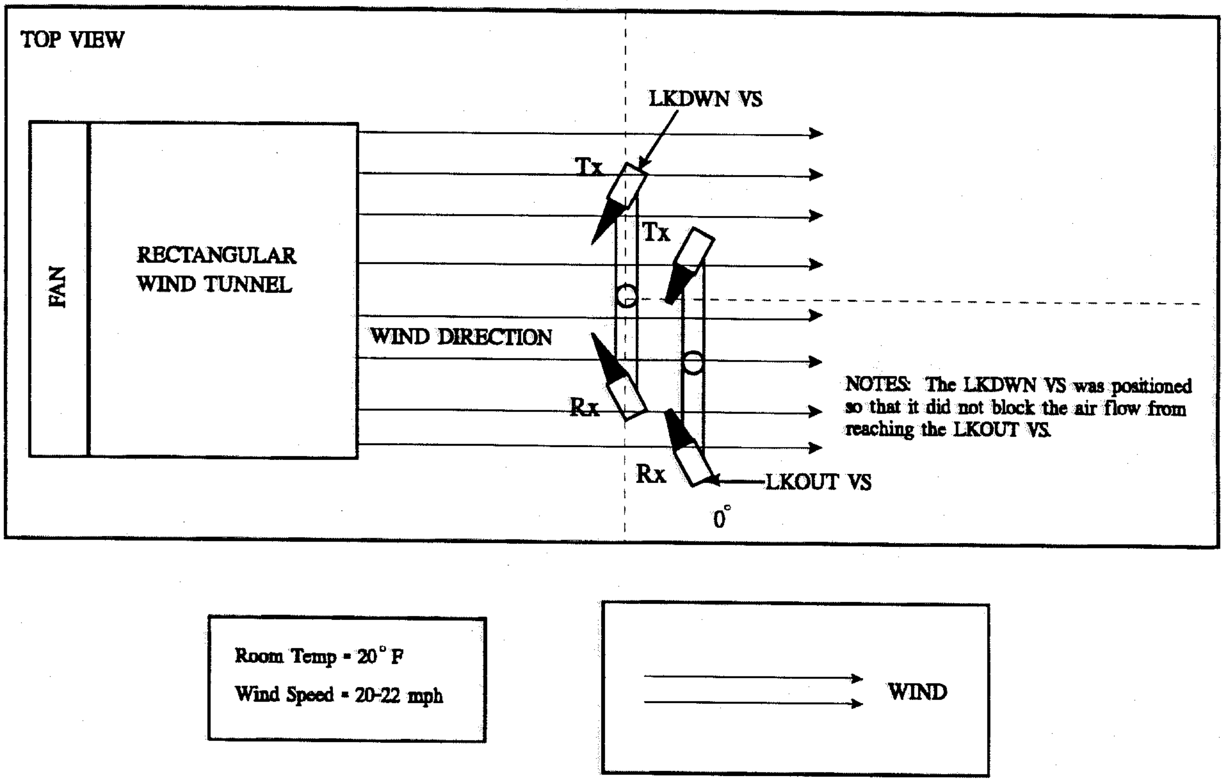


FIGURE 61. TX RX TEMP DIFF TEST 2 - LOCATION: ROWPU CHAMBER

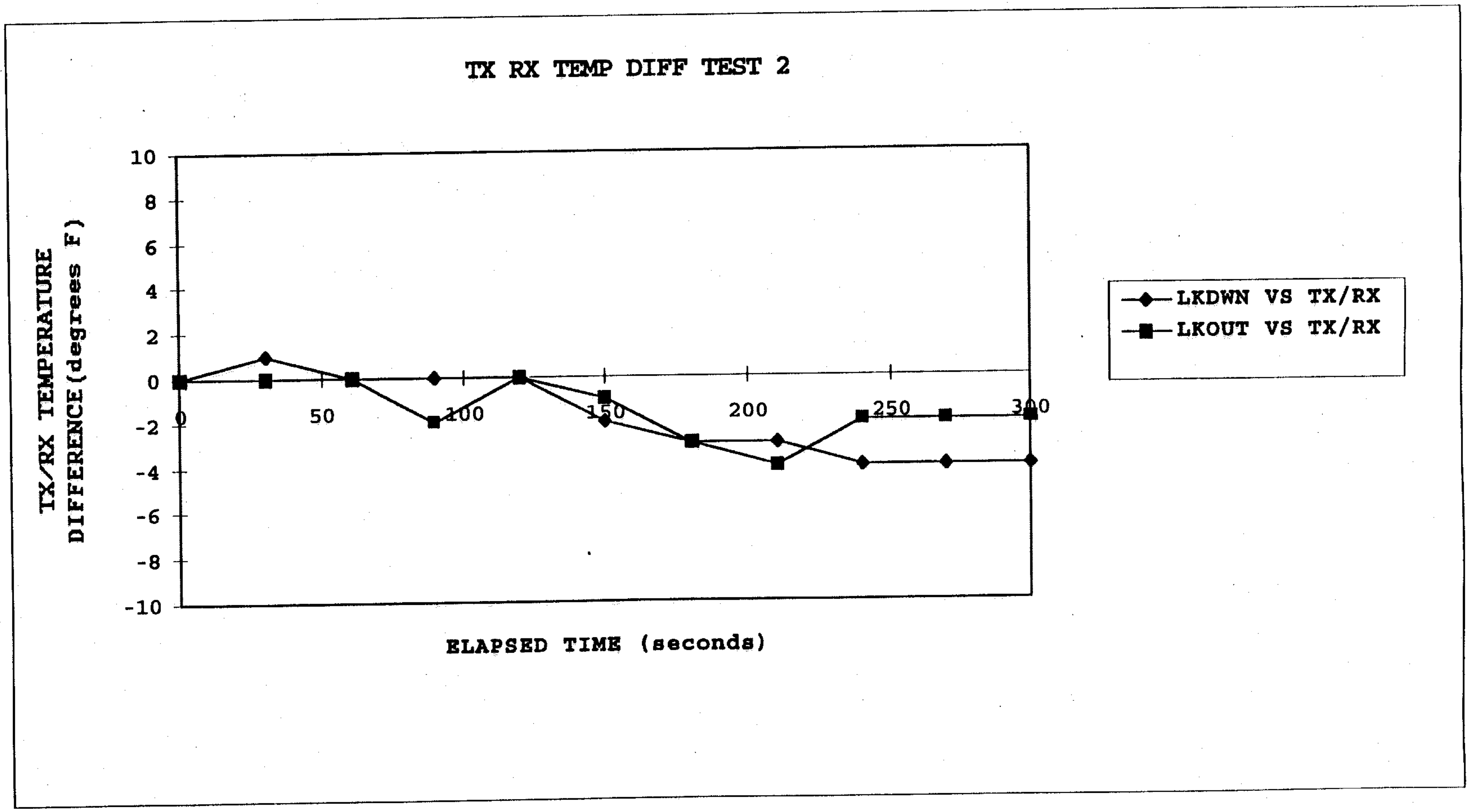


FIGURE 62. TX RX TEMP DIFF

5.5 DE-ICE HEATER CONTROL.

As discussed in paragraph 4.5.5, a potential enhancement for the Look-Down VS was additional control of the window or de-ice heaters to prevent dry snow from attaching to sensor components. These tests were designed to determine if deactivating the de-ice heaters under cold, dry snow conditions would allow the snow to naturally bounce off sensor components instead of attaching to an otherwise warmer surface.

Two De-Ice Heater Control tests were performed. Each test consisted of two parts: one which determined the sensor snow-clogging rate[10] with de-ice heaters on and one which revealed sensor performance without the de-ice heater. Testing was performed at two temperatures to aid in determining an optimum temperature at which the VS de-ice heater should be deactivated. For both tests, snow direction was determined by the angle in which the sensor appeared to be most susceptible to high window signals and clogging. Based on the Angular Blowing Snow Test results, this angle was ∠135°.

5.5.1 De-Ice Heater Test 1.

5.5.1.1 Performance with De-Ice Heater Activated.

This test was conducted on August 21, 1993, in the ROWPU Chamber. Snow was directed at the Tx from a ∠135° angle as shown in figure 63. Other test parameters included the following:

a. Chamber temperature of 1.4° F,
b. Wind tunnel air speed ranging from 20 to 22 mph, and
c. Snow rate of 48 oz./min.

5.5.1.1.1 Results.

An 80 percent snow clog was observed on the VS window after 10 minutes of testing. Despite a significantly higher snow rate, i.e., 48 oz./min. vs. 16 oz./min., window signal readings appeared to match levels attained during previous blowing snow tests.

[10]The snow-clogging rate was defined as the snow rate where the de-ice heater was just able to melt the accumulation of snow on the VS window.

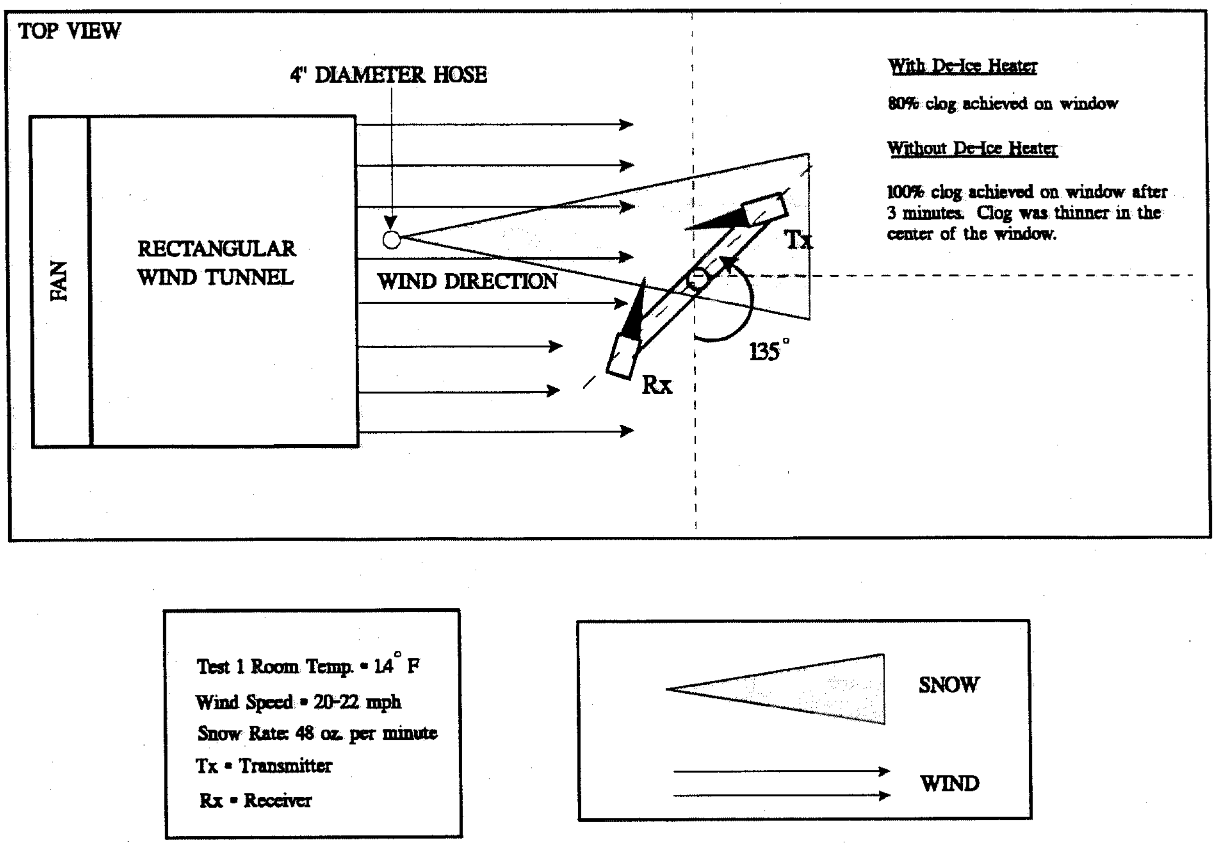


FIGURE 63. DE-ICE HEATER TEST 1 AT 135° (TX) - LOCATION: ROWPU CHAMBER

5.5.1.1.2 Conclusion/Comments.

Although a large clog was formed within the test period, the de-ice heater appeared able to prevent a total clog of the VS window. Hence, the snow-clogging rate for this test was determined to be established.

5.5.1.2 Performance without De-Ice Heater.

Test procedures were repeated with the de-ice heater deactivated and the snow rate used in part 1 of the test. A small change in temperature presented a problem for the second part of this test. The chamber temperature had decreased to -2.2° F before starting. Due to difficulties previously encountered in making small temperature changes within the ROWPU Chamber, no attempt was made to return the temperature to its initial reading.

5.5.1.2.1 Results.

VS window clogging began noticeably sooner without the de-ice heater. Furthermore, a larger clog was achieved (100 percent versus 80 percent), and in much quicker time (3 minutes versus 10 minutes) than with a functioning de-ice heater. Window signal levels reaching 167 percent indicated that sensor performance had degraded without use of the de-ice heater.

Although a larger clog formed more quickly than in part 1 of the test, the clog was noticeably thin (figure 64) in the center of the window. This same "donut" clog formation was observed in test results with the Look-Out configuration VS and the ALS (figure 65). An even larger percentage of the window was clear in those results.

5.5.1.2.2 Conclusion/Comments.

Results of test 1 indicated that the temperature at which de-ice heaters could be deactivated would have to be lower than -2.2° with the observed test conditions. The thinner clog was considered indicative of a reduced tendency for snow to stick to the sensor lens; however, the amount which did stick was still considered unacceptable.

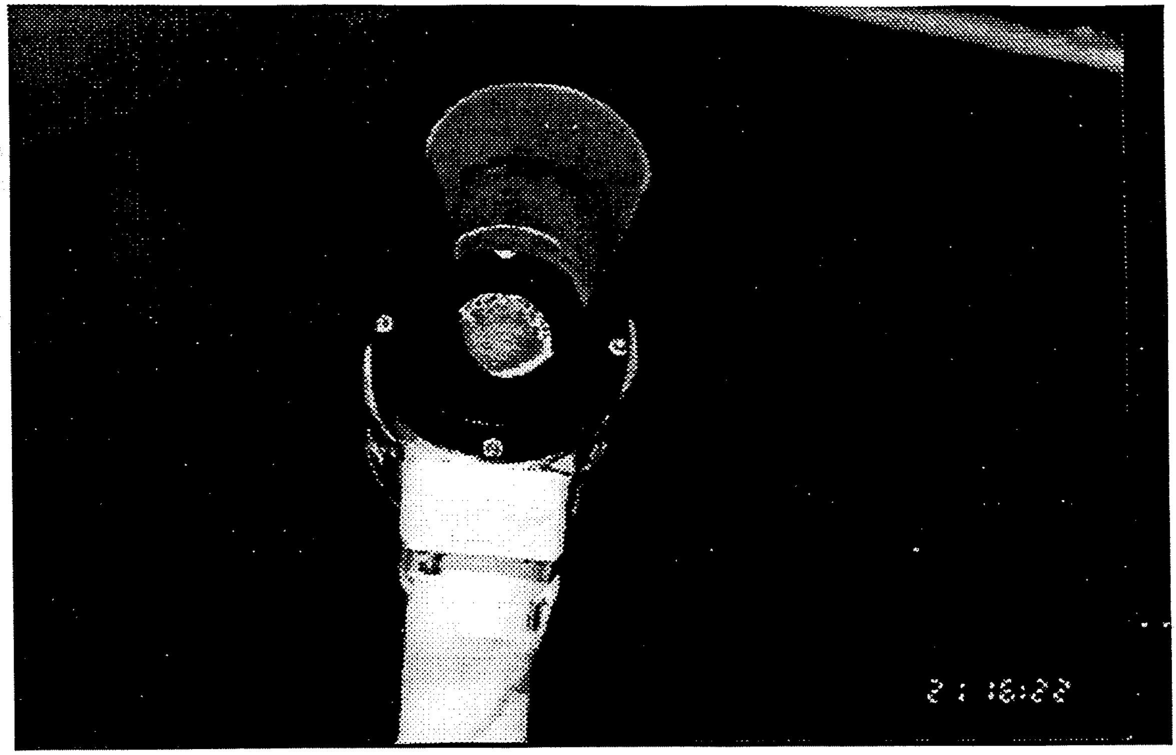


FIGURE 64. LOOK-DOWN VS SNOW CLOG THIN AT CENTER

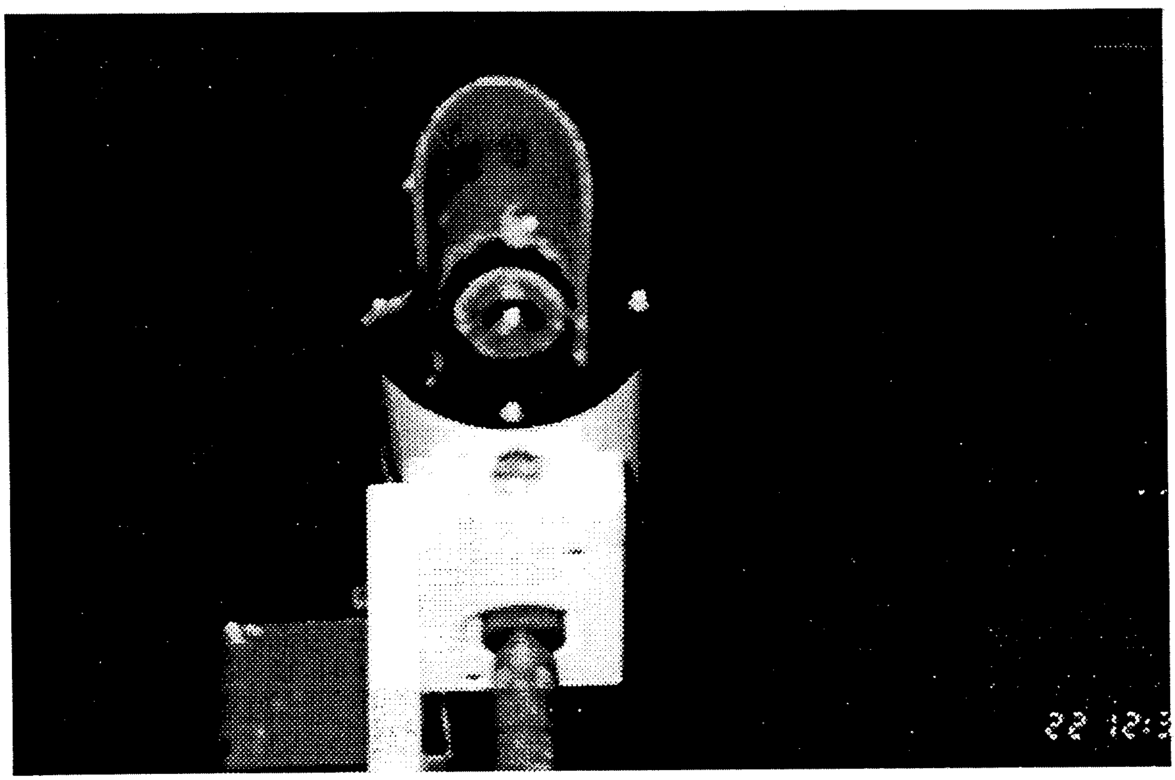


FIGURE 65. ALS "DONUT CLOG"

5.5.2 De-Ice Heater Test 2.

The intent of De-Ice Heater Test 2 was to reproduce conditions observed in the previous test but at a lower and constant chamber temperature. Additionally, the calibration plate was installed to collect data indicating the relationship between the loss in extinction coefficient with precipitation on the VS window. The effect of the calibration plate on test conduct was negligible.

5.5.2.1 Performance with De-Ice Heater De-activated.

This test was conducted on August 23, 1993, in the ROWPU Chamber. Snow was again directed at the Tx at an angle of 135° F as shown in figure 66. Other test parameters included the following:

a. Chamber temperature of -4° F,
b. Wind tunnel air speed ranged from 20 to 22 mph, and
c. Snow rate of 48 oz./min..

5.5.2.1.1 Results.

As in De-Ice Heater Test 1, window signal readings were comparable to the previous blowing snow test results despite an increased snow rate. Unlike part 1 of the previous test, a 100 percent clog was formed very early in the test. Blowing snow was terminated after 6 minutes of testing.

5.5.2.1.2 Conclusion/Comments.

The fact that a 100 percent clog was achieved after only 3 minutes of the test suggests that either the snow rate or chamber temperature was not ideal. In any case, the goal of achieving a clogging rate where the de-ice heater was just able to melt the accumulation of snow, was somewhat compromised.

Since the previous test results indicated that the optimum temperature to disable the de-ice heater would have to be colder, it was decided to conduct the second portion of this test even though the desired snow-clogging rate had not been determined.

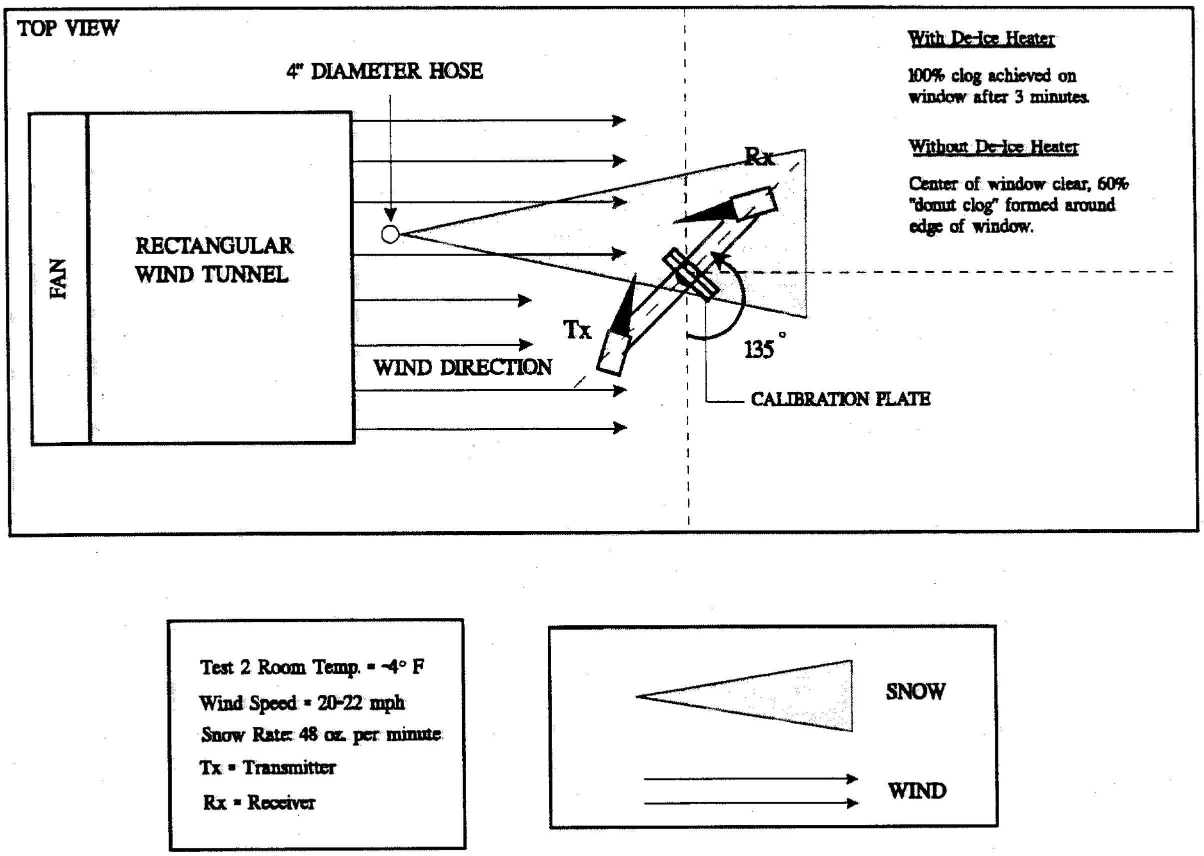


FIGURE 66. DE-ICE HEATER TEST 2 AT 135° (TX) - LOCATION: ROWPU CHAMBER

5.5.2.2 Performance without De-Ice Heater.

De-Ice Heater Test 2 continued with a deactivated de-ice heater and the snow rate used in part 1 of the test. Unlike De-Ice Heater Test 1, the chamber temperature remained constant for the entire test.

The snow spray duration totaled 5 minutes, and the wind tunnel remained on after terminating the blowing snow.

5.5.2.2.1 Results.

This test resulted in the formation of a donut clog covering approximately 60 percent of the VS window (figure 66). Additionally, window contamination signal levels peaked at 85 percent.

Despite the apparent increased resistance to clogging, it was noted that sensor recovery was slow with heaters off and the wind tunnel still activated. A thin layer of ice causing window signals of 21 percent and extinction coefficient readings of 56 km^{-1}, remained. Prior to test, extinction coefficient readings were approximately 63 km^{-1} with the calibration plate. Although this result is probably to be expected since the window heater was deactivated, the optimum heater disable temperature should result in less ice initially forming on the VS window.

5.5.2.2.2 Conclusion/Comments.

The 60 percent clog represented an improvement over the tests conducted at -2.2° and 1.4° in De-Ice Heater Test 1. Lower window signal levels (85 percent versus 104 percent) also indicated improved performance.

The results indicate that disabling the heater will improve clogging performance given snow rates and temperatures comparable to those used during testing. However, additional testing should be performed to determine an optimum temperature for shutting heaters off.

Results of tests with the Look-Out configuration and the ALS also support this theory. Other modifications such as reducing dew heater power and increasing de-ice heater power may increase sensor resistance to icing/clogging.

5.6 LOW VISIBILITY PERFORMANCE.

As discussed in paragraph 4.5.6, the Low Visibility Performance tests were essentially a comparison of extinction coefficient readings for the Look-Down VS, Look-Out VS, and an Optec transmissometer.

5.6.1 Fog Test 1.

Fog Test 1 was conducted on August 23, 1993, in the ROWPU Chamber. Based on data collected at the Otis Weather Test Facility, the Look-Down VS was calibrated with a new value of 43.9 km^{-1}. This number was 70 percent of the value used in the preceding blowing precipitation tests. The Look-Down VS, Look-Out VS, and Optec transmissometer were collocated in the center of the room as shown in figure 67.

5.6.1.1 Results.

Extinction coefficient measurements of each sensor reached 1100 km^{-1} within minutes of the test. The increase in extinction coefficient readings was too quick for any sustained comparison in sensor performance.

Significant differences in extinction coefficient measurements were noted between the Optec transmissometer and both VS prototypes. These differences grew as extinction coefficient values increased.

A time lag of approximately 1 minute was noted between when fog was injected in areas surrounding sensors scatter volume and when the sensors indicated a change in extinction coefficient readings.

It was noted that although the extinction coefficient readings were not identical for each sensor, these measurements would follow similar patterns, or track, especially in the lower extinction coefficient range (i.e., approximately 0 to 200 km^{-1}). For example, if the difference in extinction coefficient measurement was 20 km^{-1}, this offset would be relatively consistent as long as the fog densities did not increase significantly. However, once the extinction coefficient values surpassed 200 km^{-1}, the offset between the sensors grew and sensor measurements no longer tracked.

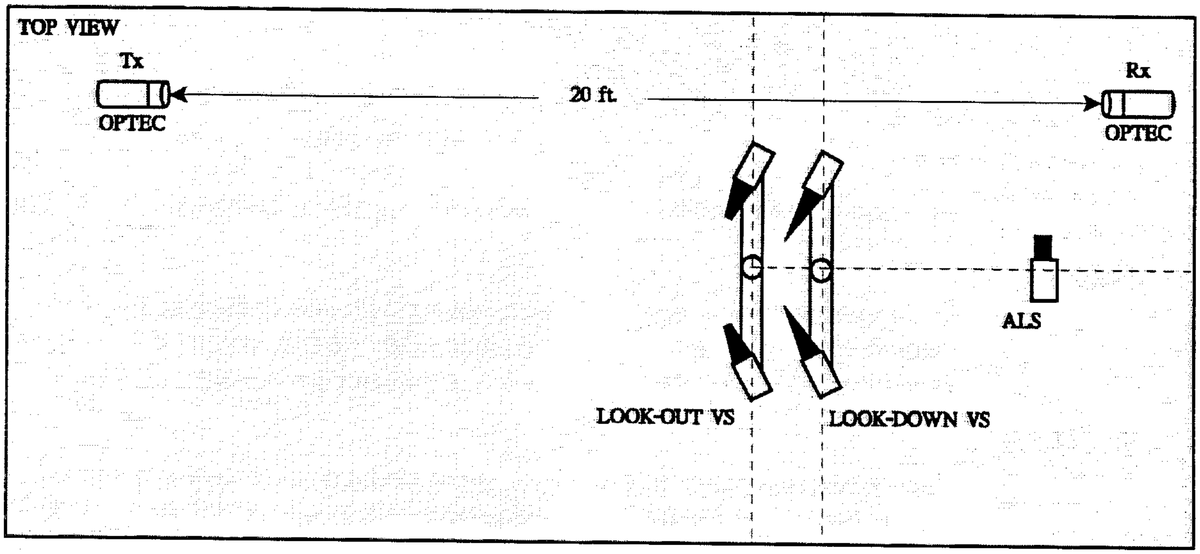


FIGURE 67. FOG W/ SNOW GUN TEST 1-3 - LOCATION: ROWPU CHAMBER

5.6.1.2 Conclusion/Comments.

Rapid and inconsistent changes in fog density at extinction coefficients above 200 km^{-1} are the most likely explanation for the lack in correlation of VS extinction coefficient readings and the noted increasing offset.

Because extinction coefficient readings of the Look-Down and Look-Out VS quickly transitioned beyond the Category IIIb range, this test was not effective for measuring sensor performance within the desired range[11] of 50 km^{-1} to 340 km^{-1}. It was concluded that quick changes in fog density readings beyond the Category IIIb range were due to an inability to effectively control the fog within the chamber.

The combination of the aforementioned factors resulted in not achieving the intended test objective.

5.6.2 Fog Test 2.

Fog Test 2 was conducted on August 24, 1993, in the ROWPU Chamber. The Look-Down VS, Look-Out VS, and Optec transmissometer were positioned as in the previous test. To attempt to increase the correlation of the VS measurements, the Look-Down VS was recalibrated to be 30 percent higher than the Look-Out VS calibration value.

5.6.2.1 Results.

Some improvement in the correlation of the sensors was noted during low extinction coefficient readings ranging from 0 km^{-1} to 200 km^{-1}. Nevertheless, as extinction coefficient values increased, tracking became more erratic. The time lag noted in the Fog Test 1 results was observed during this test also. As in Fog Test 1, problems were encountered in sustaining fog densities within the Category IIIb range.

[11]As mentioned in section 4.5.6, this extinction coefficient range was based on ambient light readings ranging from 700- to 1400-foot lamberts and runway light setting 5.

5.6.2.2 Conclusion/Comments.

Light interference between adjacent sensors may have contributed to the discrepancies noted at higher extinction coefficient levels.

5.6.3 Fog Test 3.

This test was conducted on August 24, 1993, in the ROWPU Chamber. The Look-Down VS, Look-Out VS, and the Optec transmissometer were set up as in the previous tests. In this test, a more concentrated effort was made in sustaining Category IIIb visibility for an extended period. To achieve this goal, the procedure as discussed in paragraph 4.5.6 remained, but reliable threshold points were determined for reinjecting and halting the fog production. Based on results of Fog Test 1 and Fog Test 2, fog was injected during extinction coefficients ranging from 50 km^{-1} to 60 km^{-1} and halted during extinction coefficients of 500 km^{-1} to 600 km^{-1}.

5.6.3.1 Results.

Refer to tables 6 and 7 for a breakdown of the results of this test.

The data indicated that for extinction coefficients ranging from 65 km^{-1} to 120 km^{-1} (as measured by the Optec transmissometer), there were small differences in readings for each VS prototype. The differences translate to errors of approximately 50 feet at runway light setting 5. This error is within one reporting unit; i.e., 100 feet, requirement for the New Generation RVR.

TABLE 6. VISIBILITY SENSOR EXTINCTION COEFFICIENT COMPARISON

TIME (min) ELAPSED	LKDWN	LKOUT	OPTEC	|LKDOWN - LKOUT|	|LKDWN - OPTEC|
t+0	123 km^{-1}	146 km^{-1}	109 km^{-1}	23 km^{-1}	14 km^{-1}
t+1	105 km^{-1}	125 km^{-1}	94 km^{-1}	20 km^{-1}	11 km^{-1}
t+2	81 km^{-1}	87 km^{-1}	77 km^{-1}	6 km^{-1}	4 km^{-1}
t+3	67 km^{-1}	164 km^{-1}	62 km^{-1}	97 km^{-1}	5 km^{-1}
t+4	145 km^{-1}	163 km^{-1}	120 km^{-1}	18 km^{-1}	25 km^{-1}
t+5	117 km^{-1}	134 km^{-1}	103 km^{-1}	17 km^{-1}	14 km^{-1}
t+6	91 km^{-1}	133 km^{-1}	90 km^{-1}	42 km^{-1}	1 km^{-1}
t+7	79 km^{-1}	92 km^{-1}	81 km^{-1}	13 km^{-1}	2 km^{-1}
t+8	80 km^{-1}	86 km^{-1}	70 km^{-1}	6 km^{-1}	10 km^{-1}
t+9	37 km^{-1}	52 km^{-1}	65 km^{-1}	15 km^{-1}	28 km^{-1}

The average difference along with the standard deviation of difference in extinction coefficient readings for the Look-Down VS, Look-Out VS, and the Optec transmissometer are indicated for the above measurements in table 7.

TABLE 7. CATEGORY IIIB VISIBILITY SENSOR COMPARISON

SENSOR PAIR	AVERAGE DIFFERENCE IN EXTINCTION COEFFICIENT MEASUREMENT	STANDARD DEVIATION OF DIFFERENCE IN EXTINCTION COEFFICIENT
Look-Down vs. OPTEC	11.4 km^{-1}	8.77 km^{-1}
Look-Out vs. OPTEC	33.7 km^{-1}	25.9 km^{-1}

5.6.3.2 Conclusions/Comments.

Improved fog control allowed testing to continue for a longer duration. As a result, extinction coefficient readings were able to be compared for a 10-minute interval.

The standard deviation statistic indicates that measurements from the Look-Down configuration were consistently closer to the transmissometer than the Look-Out VS. However, due to the uncertainty in factors such as relative fog density and accuracy of the Optec transmissometer, as well as the impact of these factors on visibility, no firm conclusions on sensor accuracy were possible.

5.6.4 Fog Tests 4 and 5.

These tests were conducted on August 24, 1993, in the ROWPU Chamber. For Fog Test 4, the Look-Down and Look-Out VS were placed at opposite ends of the chamber, about 20 feet apart (figure 68). The fork axis of each sensor was positioned parallel to the other. For Fog Test 5, the Look-Down and Look-Out VS were placed about 10 feet apart (figure 69) with their axis again oriented parallel to each other.

The intent of these tests was to gain additional data concerning the fog density at various locations within the chamber. Extinction coefficient readings were made at each sensor location.

5.6.4.1 Results.

Significant differences in fog density were noted at various locations of the chamber; it was also noted that sensor tracking correlation improved when the sensors were positioned close together.

As in the previous fog tests, a time lag was noted between when fog was observed in sensor airspace and when the sensor reported changes in extinction coefficient.

5.6.4.2 Conclusion/Comments.

The time lag noted in this test, as well as previous tests, is likely caused by the averaging performed by the RVR system.

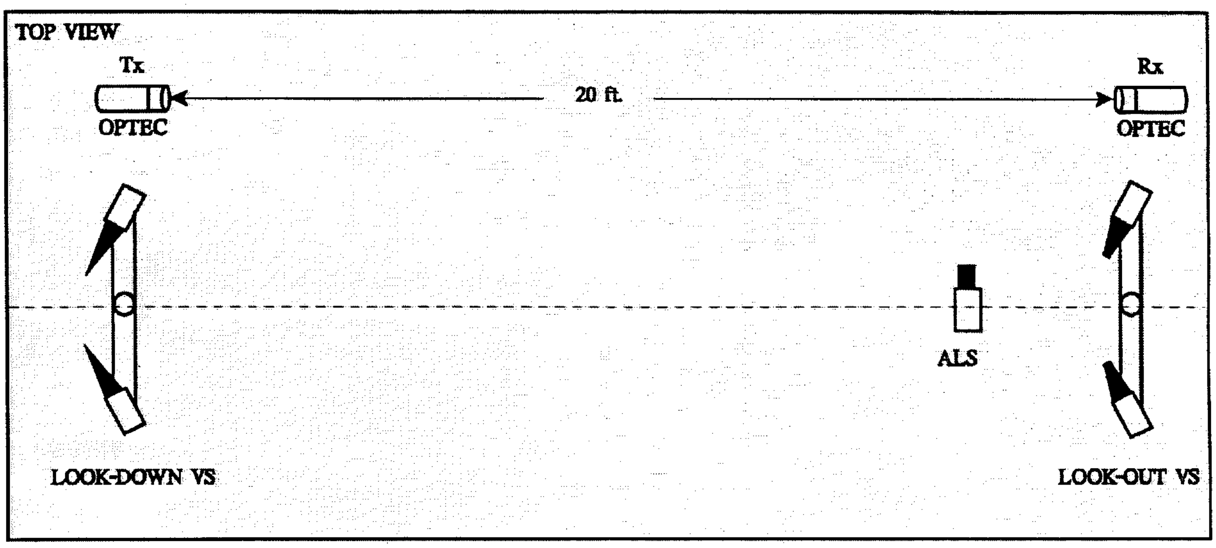


FIGURE 68. FOG W/ SNOW GUN TEST 4 - LOCATION: ROWPU CHAMBER

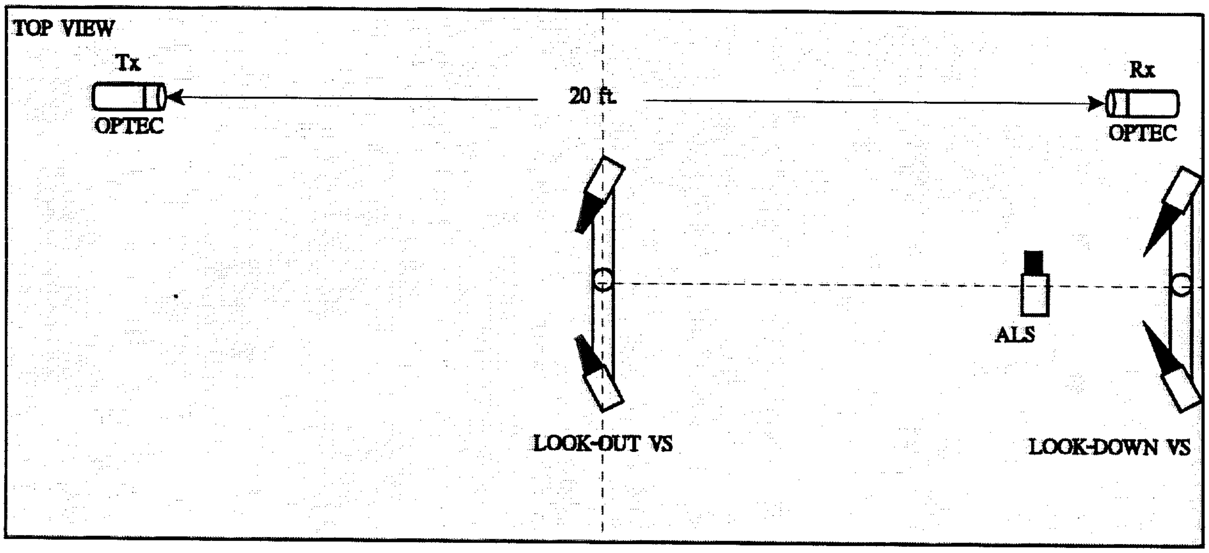


FIGURE 69. FOG W/ SNOW GUN TEST 5 - LOCATION: ROWPU CHAMBER

Because of the problems encountered in creating, maintaining, and measuring fog homogeneity, visibility measurements became somewhat arbitrary and determination of system accuracy was not possible. Due to these problems, additional tests will be needed to determine Look-Down VS accuracy during Category IIIb visibility.

6. TEST LIMITATIONS AND PROBLEMS.

During the course of CRREL testing, the following limitations and problems were noted and are summarized as follows.

6.1 BLOWING PRECIPITATION TESTS.

a. The duration of the blowing snow tests was short, typically 5 to 10 minutes. Actual conditions are likely to be more dynamic and might exceed the duration of the test scenarios;

b. Although the impact on affect extinction coefficient measurement appeared to be insignificant, icicles formed on the unheated areas of the hood and window base during many test scenarios; and

c. Look-Down VS window signals were significantly higher than expected, especially when precipitation was directed at various angles to sensor optics. In many cases, the window signals were higher than those measured by the Look-Out VS. Additional adjustments to the sensitivity of the Look-Down VS in response to window signals may need to be implemented.

6.2 LOW VISIBILITY PERFORMANCE TESTS.

a. The lack of optimum calibration values for the Look-Down VS resulted in additional difficulties in discerning actual sensor accuracy performance;

b. Due to difficulties in assuring identical fog densities at each sensor, as well as differences in sensor baselines, an undetermined amount of error was inherent in sensor visibility measurements;

c. Collocated VS and transmissometer sensors increase the probability that light interference between sensors could exist, this interference would be undetected; and

d. Due to differences in the reporting intervals between the RVR VS; e.g., every 10 seconds and the Optec transmissometer; e.g., once per minute, the visibility measurements of the two sensors may represent slightly different time periods.

7. CONCLUSIONS.

The test data supports the following conclusions:

a. The Look-Down configuration significantly increases the Visibility Sensor (VS) resistance to snow/ice-clogging;

b. The combination of the Look-Down configuration and end loaded heater blanket significantly improves VS recovery from snow/ice-clogging conditions;

c. Although separate heater controls could optimize sensor performance, the magnitude of the temperature difference between the Tx and Rx do not appear to be large enough to cause additional icing/clogging problems; and

d. Given snow rates comparable to those used during testing, VS resistance to snow/ice-clogging can be increased by deactivating its heaters at temperatures just below freezing.

8. RECOMMENDATIONS.

Although the use of the Look-Down Visibility Sensor (VS) appears to improve the New Generation Runway Visual Range (RVR) performance in inclement weather conditions, additional testing and analysis should be performed to fully verify the system accuracy and performance. In particular, extinction coefficient data should be obtained for locations around the United States that experience heavy precipitation such as snow, ice, rain, etc. This data can be used to further analyze the test scenarios and data collected at the Cold Regions Research and Engineering Laboratories (CRREL).

A portion of the blowing snow tests should be repeated for longer periods of time which resemble actual weather patterns. Testing under actual operational conditions is highly recommended.

Since no actual standard exists for Category IIIb performance measurements, several avenues of validation should be pursued to better qualify and verify Look-Down VS performance. These avenues should include laboratory tests, comparisons with Tasker systems at the Otis Weather Test Facility, and comparisons with operational Category IIIb systems, such as those in use in the United Kingdom.

9. ACRONYMS.

ALS	Ambient Light Sensor
CRREL	Cold Regions Research and Engineering Laboratories
DPU	Data Processing Unit
EPROM	Erasable Programmable Read Only Memory
EU	External User
FAA	Federal Aviation Administration
km	kilometers
MDT	Maintenance Data Terminal
mph	miles per hour
RLIM	Runway Light Intensity Monitor
RVR	Runway Visual Range
RX	Receiver
SIE	Sensor Interface Electronics
TX	Transmitter
TX RX Temp Diff	Transmitter and Receiver Temperature Difference
VNTSC	Volpe National Transportation Systems Center
VS	Visibility Sensor